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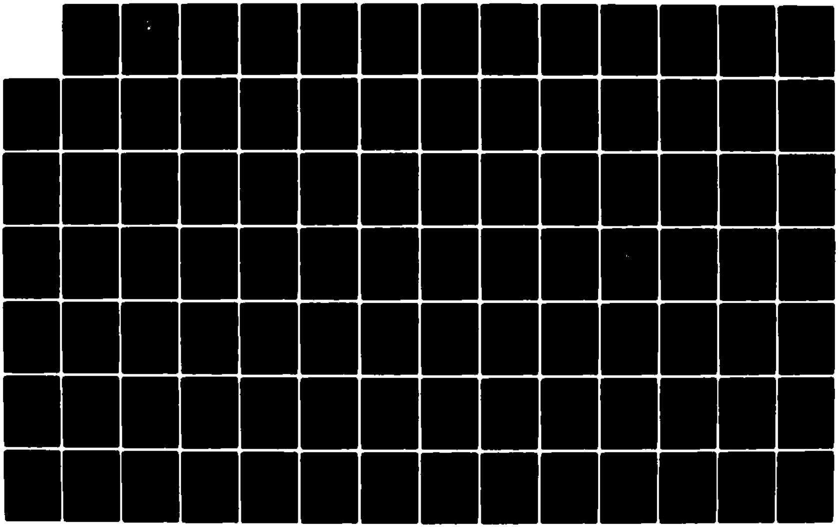

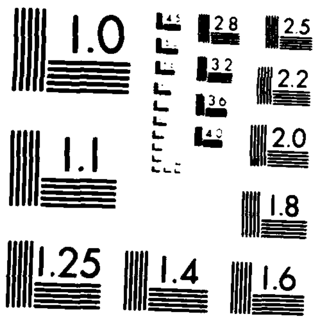

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THESIS

THE IMPACT OF MOTION AND MOTION SICKNESS ON HUMAN PERFORMANCE ABOARD MONOHULL VESSELS AND SURFACE EFFECT SHIPS: A COMPARATIVE STUDY

by

Mark A. Fisher

October 1982

Thesis Advisor: D. E. Neil

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The primary objective of this report is to present and analyze those studies that have been conducted to determine the effects of motion and motion sickness on human performance aboard vessels at sea. To accomplish this, a comparison between the motions experienced aboard several types of monohull vessels and the simulated motions of a 2,000 ton generic surface effect ship will be made. Background information concerning motion

20. ABSTRACT (continued)

sickness and recommendations for future studies are also presented.

The Impact of Motion and Motion Sickness on Human Performance Aboard Monohull Vessels and Surface Effect Ships: A Comparative Study

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ABSTRACT

The primary objective of this report is to present and analyze those studies that have been conducted to determine the effects of motion and motion sickness on human performance aboard vessels at sea. To accomplish this, a comparison between the motions experienced aboard several types of monohull vessels and the simulated motions of a 2,000 ton generic surface effect ship will be made. Background information concerning motion sickness and recommendations for future studies are also presented.

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TABLE OF SYMBOLS AND ABBREVIATIONS

NATO	-	North Atlantic Treaty Organization
SES	-	Surface Effect Ship
Hz	-	Hertz
SRR	-	Slow Rotation Room
rpm	-	Revolutions per minute
WPB	-	Coast Guard Patrol Boat
WHEC	-	Coast Guard High Endurance Cutter
SWATH	-	Small Waterplane Area Twin Hull
SSP	-	Semi-Submersible Platform
MACL	-	Mood Adjective Check List
CRT	-	Continuous Recording Trace
dBA	-	Decibels
g	-	Force due to gravity
ECM	-	Electronic Countermeasure
MSSS	-	Motion Sickness Symptomatology Severity
rms	-	Root mean square
ANOVA	-	Analysis of Variance

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I. INTRODUCTION

As long as men have put to the sea in boats, men have experienced "mal de mer," the affliction of the sea, or as we refer to it today, motion sickness or seasickness. With our present emphasis on increased defense expenditures, it would be prudent to construct our future naval combatants with regard to the impact seasickness imposes on the performance of our naval personnel.

In 1974 and 1975 the United States Navy first became aware of the fact that there existed a serious lack of data concerning man's response to high speed ship motion. Realizing that Naval personnel are the service's greatest asset, the Naval Medical Research and Development Command recognized that the degradation in human performance due to motion sickness could have a very serious effect on the readiness and combat effectiveness of our fleet. This was shown in 1974 when several NATO exercises were cancelled or altered because our ships were forced to slow to lessen the impact and damage caused by North Atlantic weather conditions. However, Soviet warships observed in the area and those ships belonging to our Allies were able to steam ahead with little or no apparent difficulty. Perhaps VADM R. E. Adamson, USN [Ref. 1] summed it up best when he shared his thoughts with the attendees at a Seakeeping Workshop. He stated that "our Naval personnel

must battle not only the most adverse of environmental conditions, but also a potential enemy threat or attack as well. Under these conditions, our sailors will fast approach their physical tolerance limit after which they will no longer be a match for any adversary."

Most of the previous research concerning very low frequency whole body motions, the incidence of motion sickness and its effects on human performance has been conducted in the laboratory. The relatively simple motion generators utilized have shown that motion sickness onset is caused by accelerating the vestibular system of the human body at low frequencies. In addition, laboratory tests have revealed that only a very few psychomotor performance tasks out of the many investigated showed any degradation due to motion or motion sickness [Ref. 2]. These findings have been inconsistent with the so far limited number of field studies aboard actual vessels at sea. The tests conducted here have revealed a degradation of psychomotor performance in a variety of tasks.

Until recently, scientists have been unable to accurately record the complex motions experienced by vessels at sea. They have also been unable to exactly duplicate laboratory tests aboard vessels in an actual sea environment. This may, in part, explain some of the contradiction between lab studies and field test results.

Although conflicting reports have been published detailing the effects of simulated and actual vessel motion on human

performance, some very good studies have nonetheless been conducted aboard small Monohull vessels and Surface Effect Ships (SES).

This paper will attempt to present some of the actual field studies and simulations that have been conducted, to analyze and compare these studies, and to make recommendations regarding future studies about vessel motion, motion sickness and their impact on human performance.

II. BACKGROUND

A. MOTION SICKNESS DEFINED

The dictionary defines motion sickness as sickness caused by motion (air, sea or car) and characterized by vomiting. However, vomiting or emesis need not be present for an individual to suffer from motion sickness. Wiker and Pepper [Ref. 3] define motion sickness as a dramatic reaction to very low frequency whole body motion.

B. MOTION SICKNESS CHARACTERISTICS

Motion sickness onset is characterized by the development of facial pallor, cold seating, nausea and emesis [Ref. 3]. In addition, an individual who is going to be sick may exhibit an increase in heart rate and possibly a reduction in blood pressure [Ref. 4]. The four main indicants previously cited generally follow a sequential pattern in most individuals. Cold sweating and facial pallor usually precede nausea, and nausea usually precedes emesis. However, some individuals exhibit behavior that does not follow the norm. Other lesser indicants of motion sickness include changes in affective state such as anxiety, depression and anger; development of gastrointestinal symptoms such as epigastric awareness, burping and an increased desire for evacuation of the bowels; and changes in neurological state such as headache, dizziness and vertigo [Ref. 3].

C. CAUSES OF MOTION SICKNESS

Decades of research have revealed conflicting reports of what actually causes motion sickness. This is in part due to the fact that differing stimuli have triggered emesis in different subjects. Early research concluded that motion sickness was related to vertical motion imposed on subjects in a motion generator. More recent studies show a relationship between various frequency and acceleration levels of vertical sinusoidal motion and the incidence of emesis [Ref. 3]. However, most everyone agrees that motion sickness is caused by the labyrinthine portion of the inner ear, or balancing organ as it is called, to be disturbed by out-of-balance movements or by sudden turning movements. The out-of-balance movements result from changes in the position of the head with respect to gravity or centrifugal force.

Visual stimuli alone can cause the symptoms of motion sickness to appear. Presentation of a visual environment which is a distorted representation of an actual environment appears to be a major factor contributing to the sickness [Ref. 5]. This is evidenced by individuals who feel nauseous after viewing movies filmed from a moving vehicle or platform whereby the viewer receives the sensation of actually being in or on the vehicle.

This paper will focus on the incidence of motion sickness caused by low and high frequency angular acceleration, since

these are the primary movements encountered aboard monohull vessels and surface effect ships.

1. Relationship with Angular Acceleration

The semicircular canals of the inner ear may interact with the otoliths in producing motion sickness. When the head is stationary under normal gravitational acceleration, the otoliths are in a resting position. Changes in the direction of acceleration acting on the otoliths due to movement of the head or due to an additional acceleration (linear, centrifugal, or Coriolis), will act to move the otoliths upon the sensory bed [Ref. 5]. The brain thus receives a signal about the perceived spatial orientation of the body, and conflicting signals may cause motion sickness.

Acceleration is the rate of change of velocity. Since velocity is a vector quantity having direction as well as magnitude, a change in either property will result in acceleration which is also a vector quantity [Ref. 6].

A vessel, monohull or surface effect ship travels through the water with a certain velocity. Therefore, individuals aboard the vessel are also travelling with this same velocity. External elements such as wind and wave action combine to alter a vessel's velocity through such forces as pitch, roll, heave and yaw. These forces thus accelerate an individual aboard the vessel in a variety of directions.

Individuals tend to exhibit increased sensitivity to motion sickness caused by linear motion in the frequency

band .25 - .33 Hz. This is sometimes referred to as low frequency motion. It appears that for high frequency motion, the dynamics of the otoliths are attenuated in such a manner as to limit input accelerations. Very low frequencies, those less than .25 Hz., also fail to exhibit a high incidence of motion sickness. Vertical reciprocating movement excites motion sickness more than a similar motion in other directions [Ref. 5].

D. ILLUSIONS OF MOVEMENT

W. H. Johnson [Ref. 7] discovered the relationship between motion sickness and head movements. In one study, 108 flight cadets were tested on a swing of length fifteen feet. The period for one complete forward and backward movement lasted approximately four seconds. Johnson discovered that all cadets who allowed their heads to move back and forth more than twenty degrees while sitting in the swing experienced some motion sickness. However, only about one-third of the cadets who moved their heads back and forth less than ten degrees experienced any sickness. In a related experiment, Johnson tested another one hundred cadets on a swing; however, these cadets had their heads strapped securely to the back of the seat. In this experiment, only five out of one hundred felt sick. These experiments clearly revealed that head movements increase the incidence of motion sickness on a swing. [Ref. 8]

1. Cariolis Illusion

The vestibular sense organs located in the head are sensitive to acceleration, and whenever an individual's head is subjected to an acceleration these sense organs transmit a message to the brain. Through learned behavior, the brain discounts most of these messages whenever the head moves. If it did not, a person who tilts his head to the right would receive the sensation of falling to the right.

This learning process over time has occurred while the body was stationary or moving only very slowly. However, when an individual is moving fast, the brain cannot ignore the signals from the vestibular sense organs. Until a person gets used to it, he will feel his body is moving every time he moves his head [Ref. 8]. This feeling of movement is called the Cariolis illusion.

2. Oculogyral Illusion

An individual is able to look at a fixed object while rotating his head because the eyes are stabilized. As the head rotates, so do the eyes. In this way, a person can continue to direct his vision at the object.

The Oculogyral illusion is produced by rotary acceleration. If a person is rotated to the right, a visual target fixed in relation to the person appears to move in that direction. This movement gradually ceases, and then it may appear to shift slowly in the opposite direction. As the person stops rotating, the vestibular sense organs behave as if the

individual was beginning to rotate in the opposite directicn. This is because deceleration is equivalent to acceleration [Ref. 8].

3. Coriolis Effect

The Coriolis vestibular reaction occurs when a subject rotates his head while he is within a rotating system. The subject may receive sensations of spinning or tilting if the head movement is in a direction that is not parallel to the axis upon which the system is rotating [Ref. 9]. The strength of the reaction is controlled by the magnitude of the angular velocity of the system and the total angle through which the subject's head is tilted. For example, if a person was seated on a chair affixed to a portion of floor that was rotated in a clockwise direction, and the person tilted his head directly toward his right shoulder, he would receive a backward tilting sensation as though he was climbing in an airplane.

E. IDENTIFICATION OF PERSONNEL MOST SUSCEPTIBLE

It is hard to pinpoint whether or not one person is more susceptible to motion sickness than another. Many studies have been conducted to determine this, and the results of these studies vary. It appears that anyone who possesses an intact and functional vestibular system and who is exposed to an appropriate force for an appropriate amount cf time will be susceptible to motion sickness. Obviously, the variables that dictate to what degree a person is susceptible

are the amount of force the person is exposed to and the duration of exposure. Data from historical questionnaires reveals that up to ninety percent of the population sampled had at one time or another suffered from some type of motion sickness [Ref. 3].

Learning and conditioning may decrease or increase an individual's susceptibility to a particular kind of motion sickness. For example, a person who is moderately susceptible to motion sickness may have conditioned himself to be relatively resistant to seasickness by frequently traveling aboard ships in mild and rough sea conditions.

However, in another instance, a person who is moderately susceptible to motion sickness may be extremely susceptible to car motion. This may be a result of having been sick a number of times while riding in an automobile. An individual can get so conditioned to becoming sick that even a faint smell of gasoline when getting into an automobile may produce a mild feeling of discomfort and apprehension [Ref. 8].

It has been determined that people with defective vestibular sense organs are less likely to be susceptible to motion sickness than are people with normally functioning vestibular systems. Additionally, people who have learned to hold their head still while traveling in a moving vehicle are also less likely to feel ill.

F. EFFECTS ON HUMAN PERFORMANCE

In controlled laboratory experiments using a vertical motion generator for a period of twenty minutes, no post-exposure decrements in performance were noted in subjects who were given the following tasks: running, dart throwing, speed and accuracy rifle shooting, code substitution and mirror drawings. Only the Mashburn Complex Coordinator, a type of tracking task, caused a significant postexposure decrement in the test subject's performance [Refs. 3, 10, 11, 12].

Slow Rotation Room (SRR) studies during which test subjects were exposed to rotary environments between 1.7 and 10 rpms continuously over various numbers of days have been conducted. Except during emesis, the test subjects showed no degradation of performance in grip strength, combination lock opening, arithmetic computation, dial setting, Whipple Steadiness Test, card sorting, dart throwing and ball tossing [Refs. 3, 13, 14, 15].

During another laboratory test, performance by experienced sailors was measured after being exposed to a sea motion simulator. The experiment simulated sea states 0, 3, 4, 4.5 and 5. Emesis was first observed at sea state 4.5, but the incidence of motion sickness was greatest at sea state 5. No performance decrements were observed in tasks such as target classification, turn count tests, sonar detection, Doppler tests, memory tests and reading comprehension tests [Refs. 3, 17].

However, in stark contrast to these results, Money [Ref. 17] reports other simulated motion studies and tests similar to the Slow Rotation Room have revealed the following changes in human behavior and performance:

1. Decreased spontaneity, inactivity, or being quiet or subdued.
2. Carelessness in performance of routine duty.
3. Decreased muscular coordination.
4. Decreased performance with an electronic tracking apparatus.
5. Decreased performance with a "pursuit meter."
6. Decreased performance with a hand dynamometer (squeezing ability).
7. Decreased ability to estimate time.
8. Decreased performance of arithmetic computation.

Sapov and Kuleshov [Ref. 18] analyzed actual ship motion effects on crew performance over an extended time period. The performance factors measured were physical efficiency, mental efficiency and professional efficiency.

Aerobic measures and static muscle strength tests served to evaluate a person's physical efficiency. Mental efficiency was measured through the use of mental arithmetic tests, Landolt's Ring Test, rearrangement of jumbled numbers, tracking tests and visual reaction times. Professional efficiency was evaluated by comparing how quickly the test subjects performed tasks associated with their specialties under test conditions, with how quickly these same tasks were performed by their contemporaries under normal conditions.

The test lasted six weeks and was performed in the following manner. First, the vessel steamed for one week in a sheltered bay. Test subjects were evaluated, and results were tabulated. Then the vessel steamed outside the sheltered bay for a week, and again personnel were evaluated and results documented. Immediately following this second stage, the vessel put out to sea for three weeks, and personnel were again observed.

The findings revealed a significant degradation of performance in all three factors during the second stage of the test, while small improvements in mental and professional efficiency were recorded during stage three. However, these improvements were below the control levels established during stage one of the test. Physical efficiency continually declined throughout the entire period. This was attributed to the physical exertion expended by the subjects in coping with the pitching and rolling of the ship. The reduction in mental and professional efficiency was seen not so much as a reduction in quantity of work, but rather as a reduction in quality of work. [Refs. 3, 19]

G. PHYSIOLOGICAL EFFECTS

1. Fatigue

Long term exposure to actual vessel motion places considerable demands on the body's musculoskeletal system to maintain an erect posture. This, in turn, will speed up the

onset of fatigue. To combat this onset, the body increases certain hormonal output that in turn increases cardiac output and pulmonary ventilation, elevates blood glucose, and redistributes the body's blood supply from nonessential areas such as the skin and mucous membranes to tissues of greater survival importance such as the skeletal muscles and brain. [Ref. 3]

H. EFFECTS ON AFFECTIVE STATE

In addition to fatigue, other affective states that have been examined during past research are: anxiety, aggression, surgency, elation, concentration, sadness, skepticism, egotism and vigor. Since vessel motion as a stimulus may alter an individual's moods, there exists the possibility that such mood changes may cause decrements in the individual's performance. Wiker, Pepper and McCauley [Ref. 2] have determined that changes in affective state may have several consequences such as:

1. Be advantageous or disadventageous in an individual's attempt to deal with vessel motion.
2. Alter managerial or leadership effectiveness.
3. If continuously negative, may yield coping behaviors which interfere with organizational gcals.
4. Lead to direct or indirect physiological changes such as sleep loss or cardiovascular changes that may in turn affect the long or short term health of the individual.

Abrams et al. [Ref. 16] determined that continuous exposure to motion and the onset of motion sickness reduced vigor in test subjects. Other test subjects have reported apathy, depression, and anxiety while experiencing motion sickness [Refs. 2, 13, 15, 16].

III. COMPARISON OF HULL TYPES

A. MONOHULL

1. Description

As previously stated, much of the early research to determine the effects of motion sickness on human performance was conducted on or aboard motion generators. These machines were designed to simulate the most frequently encountered forms of vessel motion such as pitch, roll and heave.

McLeod et al. [Ref. 19] conducted various performance tasks utilizing the Warren Spring ship motion simulator. This simulator was driven in heave, pitch and roll by signals taken and recorded aboard the frigate HMS AVENGER. The frigate displaced 2,040 tons while steaming at 25 knots into a force 4 wind.

Wiker and Pepper [Ref. 3] performed an actual field evaluation aboard a Coast Guard 95' Patrol Boat (WPB), and Wiker, Pepper and McCauley [Ref. 2] conducted another field test with the same WPB, a Coast Guard 378' High Endurance Cutter (WHEC) and an 89' U.S. Navy Small Waterplane Area Twin Hull (SWATH) vessel. The WPB and WHEC are both monohull vessels, while the SWATH vessel is a catamaran or twin-hulled ship.

The 95' WPB has a beam of 19.9', a draft of 6.0', a displacement of 100 tons, a cruising speed of 12-15 knots and

a crew of 17 men. The 378' WHEC has a beam of 42', a draft of 20', a displacement of 3,000 tons, a cruising speed of 18 knots and a crew of 140 men. The 89' SSP SWATH vessel carries a beam of 47', draws 15.5' and displaces 217 tons. This vessel has a design speed of 15-18 knots and a crew complement of 10 men.

2. Test Subjects

McLeod et al. [Ref. 19] tested eight males and two females who were not members of the military and who all claimed not to be prone to sea sickness. These test subjects ranged in age from 23-60 years.

Wiker and Pepper [Ref. 3] selected six subjects from the 95' WPB's existing crew for their preliminary tests. The six chosen were all enlisted personnel, and the following criteria were used for their selection: no chronic motion sickness history; at least six months previous sea duty aboard the vessel; not on any medications or habitual users of alcohol or tobacco; and a willingness to give up four days liberty to stay in the controlled environment. As it turned out, all test subjects were male, all were about the same age and weight, all were in good health and all were about equal in educational and physical performance.

Aboard the WHEC, Wiker, Pepper and McCauley [Ref. 2] selected eighteen male volunteers based on the same criteria. None of their test subjects smoked and all reported average

susceptibility to motion sickness. Again, they were all about the same age and weight, and all were reported in good health.

3. Tests Conducted

Through such tasks as tracing, tracking and keyboard digit punching, McLeod et al. [Ref. 19] strove to parcel out the effects on human performance caused by motion sickness from the effects on human performance caused by the simulated ship motion itself.

a. Tracing Task

The tracing task required each test subject to trace a variety of patterns that were drawn on a sheet of paper attached to the wall at shoulder height. Subjects were directed to perform the task while standing, and were not allowed to steady themselves by holding onto the wall. On each trial a set of six tracings was completed, and the subjects were rated on both accuracy and time to complete each set. [Ref. 19]

b. Tracking Task

The tracking task consisted of a 100 mm x 80 mm screen on which was projected a circle of radius 2.5 mm and a cross with an arm length of 5 mm. Test subjects were placed 60 cm from the screen. Upon receipt of a start signal flashed on the screen, they were required to follow the random movement of the circle by placing and keeping the cross within the circle for the duration of the trial. The subjects accomplished this through the use of a pressure sensitive,

non-movable joy-stick or a spring-centered, movable joy-stick that controlled the movements of the cross. Subjects were graded on time to acquire the target and mean error after target acquisition, where acquisition was defined to be aligning the center of the cross within 5 mm of the center of the circle for a period of 1 second.

c. Digit Keying Task

For the digit keying task, the test subjects were shown a series of four digit numbers on the display of a conventional calculator keyboard. They were directed to first say the number, then to enter the number with four keystrokes. The keys on the test apparatus were 9 mm square, and each was separated from another by a length of 6.5 mm. Test subjects were scored on the time to completion and number of errors per series of keystrokes.

The intent of Wiker and Pepper's tests [Ref. 3] aboard the 95' WPB was to study the effects of motion on short term memory, pattern recognition, sentence comprehension and mathematical reasoning. In order to adequately measure these parameters, and with regard to the missions of the patrol boat, the following tests were selected: navigation-plotting, tracking, letter search, Spoke test, complex counting, code substitution and grammatical reasoning.

d. Navigation-Plotting Task

The navigation-plotting task required test subjects to plot the relative movement of a target vessel and to

compute that vessel's relative course, speed and closest point of approach. Subjects were allotted nine minutes to perform as many computations as possible. The results were scored based on the accuracy of the computations and the number of computations completed.

e. Critical Tracking Task

The tracking task administered was the critical tracking task. This task required the subjects to monitor and stabilize a highly reactive needle within the center of a meter type display. Compensatory corrections against random needle movements were made via a free turning control knob located beneath the meter display. Five trials were performed during each test period, and the resultant score was digitally displayed, indicating the test subject's critical tracking limit.

f. Letter Search Task

The letter search task required test subjects to directionally search five-letter groups arranged in four columns of sixteen groups for a prespecified letter, or for one of up to four prespecified letters. Three trials by each subject were performed after scanning stimulus sheets for twenty to thirty seconds.

g. Spoke Test

The Spoke test consisted of a sheet of paper with a small circle drawn in the middle. This center circle was surrounded concentrically by a series of similar circles which

were equidistant from the center and evenly distributed along the periphery. Thirty-two numbers, 1-32, were randomly distributed throughout the peripheral circles. Test subjects were required to move a pencil from the center circle to the peripheral circle labeled number 1 and back to the center again. They continued in this fashion in numerical order until all thirty-two numbers were located. Time of completion was logged on the data sheets.

h. Complex Counting Task

The complex counting task required subjects to listen to three different tones repeated in random fashion on a tape recorder. They were required to keep a mental count of the two lower tones' occurrences. When one of the lower tones was heard four times, the test subject recorded this on a data sheet and "reset" his mental counter for that tone. The tones were presented over a ten minute period, and the test subjects were graded on absolute errors in recording the number of quads of the two lower tones.

i. Code Substitution Task

Code substitution tests required the test subjects to substitute a numeric array for an alpha array based on the coding matrix provided. These tests were administered in two minute periods and performance was measured based on the total number of items coded.

j. Grammatical Reasoning Task

In the grammatical reasoning test, the subjects were given a sheet of paper that had thirty-two sentences written on it. These sentences described various relationships between two letters, A and B, and at the end of each sentence A and B were placed as AB or BA. The test subjects then had one minute to read the sentences and decide if they were valid or not. Test scores were based on the total number of sentences correctly diagnosed.

k. Mood Adjective Check List (MACL)

The Mood Adjective Check List was designed to measure ten effective states, or types of moods. For each type of mood, three adjectives were listed that described the mood and have been shown in the past to be good mood indicators. The test subjects were then instructed to check the adjective that most closely described the degree to which he was affected by each mood listed.

Wiker, Pepper and McCauley [Ref. 2] used the navigation-plotting task, the code substitution task, the complex counting task, the critical tracking task, the Spoke test and the time estimation test in their studies aboard the 378' WHEC, the 95' WPB and the 89' SSP. The first five tasks were conducted in the same manner as was previously mentioned.

l. Time Estimation Test

In the time estimation test, the subjects were given a list of time intervals that they had to produce.

These intervals ranged from two to twelve seconds in duration. The test subjects produced these intervals by pressing a key that automatically activated and time coded a magnetic tape. The subjects were permitted to count to themselves, but they were not given any feedback about the accuracy of their time estimates. Each administration of the test consisted of forty randomly ordered trials with five sets of time intervals. The test was scored by comparing the actual duration of the time interval with the test subject's estimation of that particular interval.

4. Test Procedures and Equipment

The experimental cabin used by McLeod et al. [Ref. 19] was fully enclosed so that the test subjects received no visual cues from the motion generator. During the tracking and key punching tasks, a subject was strapped into a modified helicopter seat facing a console that contained the CRT display. Forearm restraints, the joy-stick and the numerical keyboard were attached to the deck of the console, while the tracing patterns were pinned to the rear wall of the cabin. The forearm restraints were only utilized during the tracking task. Each test subject was able to communicate with the experimenters via headphones, while a closed circuit television camera continually monitored the subject's progress.

The tests conducted by Wiker and Pepper [Ref. 3] aboard the 95' WPB were administered on the cutter's mess deck. This area provided adequate room and ventilation and

represented one of the compartments least affected by the vessel's motion. Initially, the battery of tests was conducted while the vessel's engines were running; however, the cutter was still tied to the pier. In this manner the experimenters were able to establish some static level control scores for each test subject, while the subjects themselves became familiar with the tests.

Underway data was collected on the two successive days after dockside control data was recorded. The vessel was underway for the exact same time period and in the exact same place each day. When testing commenced, the initial course was directly into the primary swell. Course changes of 45 degrees clockwise were then consecutively made every thirty minutes, and tests were conducted on each leg. Throughout the test period of eight hours, the vessel steamed in two octagonal patterns at 10 knots. After the second day of steaming, the test subjects filled out a questionnaire giving their own subjective evaluations about which motions they thought impacted on their performance the most.

Wiker, Pepper and McCauley [Ref. 2] familiarized their test subjects with all performance tasks for one week before the experiment was conducted. After this familiarization period, the battery of tests was administered for six consecutive days in the following manner: two days of testing at dockside, followed by three days of testing at sea, and concluding with a final day of testing at the pier.

During the days spent at sea, the vessels followed the same time frame and steaming tactics as enumerated earlier, but the speed utilized was seven knots vice ten knots. Again, data taken while the vessel was moored pierside was recorded between 0800 and 1600.

The test subjects were grouped into two-man teams and randomly assigned so that each team spent one day at the pier and one day underway on each of the test vessels.

B. SURFACE EFFECT SHIP (SES)

Although no actual field studies have been performed aboard surface effect ships, the Office of Naval Research has performed two extensive studies using a motion generator at Human Factors Research, Inc. in Goleta, CA [Ref. 20]. These studies simulated the heave, roll and pitch motions that would be encountered by a 2,000 ton SES operating in sea states 3, 4 and 5 at speeds of 80, 60 and 40 knots respectively.

In Phase I, Malone [Ref. 20] reports that four crewmen who had previous duty aboard a Navy SES or who had previous exposure to a motion generator were tested. The test periods lasted from one-half to four hours in duration, and the men were subjected to the simulated motions stated previously. As the crewmen were able to adapt to the motion, exposure time was increased to between 36 and 48 hours. These seasoned crewmen were again gradually able to adapt to the motion

environment and were able to perform such functions and tasks as eating, moving about, sleeping, navigation-plotting, cryptography, auditory vigilance, lock opening, keyboard operations, tracking and equipment maintenance and repair.

Malone [Ref. 20] found that although there was some general muscle and eye fatigue, the crew's performance showed no significant degradation over time. The experimenters, however, decided more tests were needed because the sample crew was small in number and highly motivated professionally, and the motion generator was not providing the desired velocity and acceleration after a larger cabin was installed. This led to Phase II, about which this discussion will center.

1. Description

The Phase II test apparatus consisted of the redesigned motion generator and cabin and an identical cabin that remained stationary. Temperatures within the cabins were controlled between 70-76 degrees Fahrenheit, and noise levels were maintained in the motion generator cabin at 69-73 dBA and in the static cabin at 67-71 dBA. The motion generator simulated a heave velocity of plus or minus 18 ft/sec and an acceleration of +1.0 g. up and -0.9 g. down in the bandwidth 0.1 to 5.0 Hz. It also simulated a pitch and roll rate of plus or minus 25 deg/sec and an acceleration of plus or minus 150 deg/sec^2 in the bandwidth 0.1 to 4.0 Hz.

2. Test Subjects

Malone [Ref. 20] reports that the test subjects for Phase II were carefully screened to ensure that they were free from any physical defects that might make them susceptible to serious injury. Most test subjects were recent graduates of boot camp and all had a functional and intact vestibular system. Initially, the subjects were placed in three teams with seven men in each team. Four men from each team were selected as the primary test group, while the rest of the team members served as backups.

3. Tests Conducted

The tests selected by Malone [Ref. 20] were those that most closely simulated tasks that would normally be performed aboard an SES. Although the scenarios presented were not complicated, they proved to be a more than adequate challenge for the relatively inexperienced test subjects.

Subjects were allowed to familiarize themselves with the various tasks during several practice sessions.

a. Electronic Countermeasure (ECM) Tracking Task

This task was very similar to the Critical Tracking Task. The test subject was again required to center a needle on a meter type display while keeping his arms outstretched and unrestricted in movement. The instability of the needle was steadily increased to simulate a decreasing enemy range. However, during this test the subject was provided positive feedback by the equipment if he performed well.

In addition, each test subject was promised a prize if he achieved a certain test score or better. Each subject completed five trials per run, the duration of which lasted four to eight minutes.

b. Dual-Axis Tracking Task

This task was very similar to McLeod's tracking task. Here the test subjects attempted to control a simulated weapon using a two-axis joy-stick. The test required each subject to direct the fire of the simulated weapon by centering a blip both vertically and horizontally on a CRT display. Each trial lasted two minutes; however, the first ten seconds and the last ten seconds were not scored in order to discount starting and ending effects. Each test was comprised of three such trials.

c. Keyboard Task

The purpose of this task was to determine how motion might affect a crewman's ability to perform keying functions on a typical small on-board computer. Each test subject was required to determine the risk of collision of an approaching target on a wall-mounted minicalculator. He managed this by computing the target's time-to-intercept, closure rate, speed and relative bearing. Each test subject was given three problems, and he was afforded knowledge of the results of his computations at the conclusion of the three trials. Performance was measured by computing the subject's

mean time to complete the three problems. Number of wrong answers and number of recognized miskeys were also recorded.

d. Lock Task

This consisted of a relatively simple task of opening a four-number combination lock, utilizing only one hand while holding the arm outstretched. Performance was measured by logging the total time required for each test subject to correctly open the lock. Additionally, the number of restarts required was also recorded. The duration of the test was approximately five minutes.

e. Maintenance Task

This task was a measure of a crewman's dexterity in that each test subject was required to remove mechanical and electrical parts such as screws, nuts and resistors from a common circuit board. Subjects were allowed to use only a pair of needle-nose pliers, a screwdriver and a soldering gun to accomplish the task. A maximum of 30 minutes was allotted to each subject for the test, and a performance score was assigned, giving undamaged parts removed twice the weight as parts removed that were damaged.

f. Load Task

In this test, a 14 pound wooden box encased in a large canvas bag was passed to a test subject through a side hatch in the test cabin. The subject then maneuvered the box through various load-handling exercises. Afterwards, the box was returned to the canvas bag and delivered back to the

experimenters through the same hatch. No score was assigned to this task because no useful performance metric could be measured.

The above mentioned tasks were designed to measure a crewman's musculocoordination and control. However, an individual's cognitive processes are also subjected to possible performance degradations caused by motion and motion sickness. The following tasks were initiated to determine to what extent attention, perception and memory are affected by simulated SES motion.

g. Missile Detection Task

This task was designed to simulate a typical radar watch where the operator was required to detect incoming surface-to-surface missiles. Normally the frequency of such contacts is quite low; therefore, monotony is a common factor that limits an individual's effectiveness. The missile displays were presented at random bearings on the periphery of a nine inch CRT with continuous video noise. The image then moved on a straight line course to the center of the scope. Each test subject pushed a button upon detecting an incoming missile, then verbally passed the missile's present bearing. A subject's performance was based on the number of times the contact was "painted" before being detected. False detections were also scored. A test consisted of six contacts generated in a ten minute pretest, followed by a two-hour period where six contacts were simulated every twenty minutes, and concluded

with a ten minute post-test in which six contacts were again presented.

h. Collision Avoidance Task

This task was designed to measure an individual's attention span and ability to make perceptual discriminations about impending ship collisions in a heavily congested area. Again, a test subject viewed a radarscope, but in this test the display represented what would be viewed from the vessel's centerline to 60 degrees right and left of center. The center of the scope was now represented at the bottom of the display, and the sweep line mapped out the 120 degree sector in 1.67 seconds. The sector contained 18 to 25 contacts, and no video noise was added. Although most contacts posed no immediate threat, simulated course changes by these contacts altered that state. Additionally, other contacts appeared at the periphery of the scope and were programmed for a collision course. The test subject was required to again hit a button when he detected a threatening contact, and then verbally pass that contact's approximate bearing and range. Performance was measured as a percentage of collision courses still to be traversed before an actual collision occurred. Each test was comprised of four 30-minute test periods and six threatening contacts were presented per period.

i. Cryptographic Coding Task

Similar to Wiker and Pepper's [Ref. 3] Code Substitution Test, these tasks were designed to measure near-field

vision, character recognition and an individual's own powers of motivation to perform routine and sometimes tedious work. Test subjects were given a sealed envelope containing a message of 200 letters arranged in two columns of ten characters each and a coding matrix. They then had to encode or decode the ten characters by using each successive pair of message letters, beginning left to right, to enter the appropriate row and column of the coding matrix in order to extract the correct character code from the body of the matrix. In this manner, the entire message was encoded or decoded and transcribed on a separate page. The transcribed message, coding matrix and coded message were then resealed in the envelope and delivered to the experimenters. A 16-minute time limit was imposed on the test subjects, and their performance was measured as the mean time in minutes that it took to transcribe the message in a single trial.

j. Navigation-Plotting Task

While not as complex as Wiker and Pepper's [Ref. 3] Navigation-Plotting Task, Malone's [Ref. 20] task was closely patterned after those actually performed by radar plotters on the bridges of U.S. Naval vessels. The task was designed to test an individual's attention, perception, memory and fine motor skills under the pressure associated with receiving information in a rapid manner. Test subjects were required to plot their own ship's course as well as periodic radar contacts. Each subject was presented with 29 radar

contacts and a course change for their own vessel during the 30-minute test. Performance was measured by obtaining the average distance error between plotted and actual contact positions.

k. Visual Acuity Test

This test required subjects to read aloud printed material that had been previously fixed to the cabin wall. Each subject maintained his head a fixed distance from the wall but was permitted head movement in a vertical direction. Test material was divided into 17 sections, and character size varied in distinct steps from one section to the next. For instance, when the subject's head was 36 inches from the wall, the visual angle subtended by the largest characters was 11.28 minutes of arc while that of the smallest characters was 2.82 minutes of arc. Test subjects would read the section with the smallest characters that they could visually determine and report that section number to the experimenters. The experimenters would grade the subject's performance based on the accuracy with which he read the printed material.

4. Test Procedures and Equipment

The motion generator used by Malone [Ref. 20] was controlled by a digital-to-analog computer that input detailed motions for a 2,000 ton SES. Tests were conducted under simulated motions in sea state 3 at 80 knots, in sea state 4 at 60 knots and in sea state 5 at 40 knots. All test runs lasted

20 to 48 hours except during mechanical failures, test subject aborts and certain scheduled six hour runs.

Formal work/rest schedules were designed for the test subjects. This allowed the subjects to complete the various tasks, to attend to normal life support functions and to relax and take part in some form of recreation. The schedules also afforded the experimenters time to record certain physicological variables about the test subjects. The schedules for each pair of test subjects were devised so as to avoid any interference that might occur due to the confines of the small test cabin.

IV. RESULTS

A. MOTION SICKNESS

In the experiments conducted by McLeod et al. [Ref. 19], none of the test subjects actually reached the stage of emesis; however, nearly everyone reported a small decrease in their feeling of well being. Other indices of motion sickness such as dizziness, sweating, headache, stomach awareness and salivation showed no appreciable change over static pre-motion and actual motion environments.

Wiker and Pepper [Ref. 3] computed a motion sickness symptomatology severity (MSSS) score based upon their test subjects' answers to a questionnaire that was administered during each test cycle. They discovered that MSSS scores were associated with the course changes aboard the 95' WPB, and these results are indicated in Figure 1. A test using the Students-t statistic showed motion sickness severity was greater ($p < .05$) on steaming legs into or toward the primary swell than legs steaming with or down the primary swell. Additionally, episodes of emesis were recorded and these too were more frequent when the vessel was heading into the primary swell. A plot of this is shown in Figure 2.

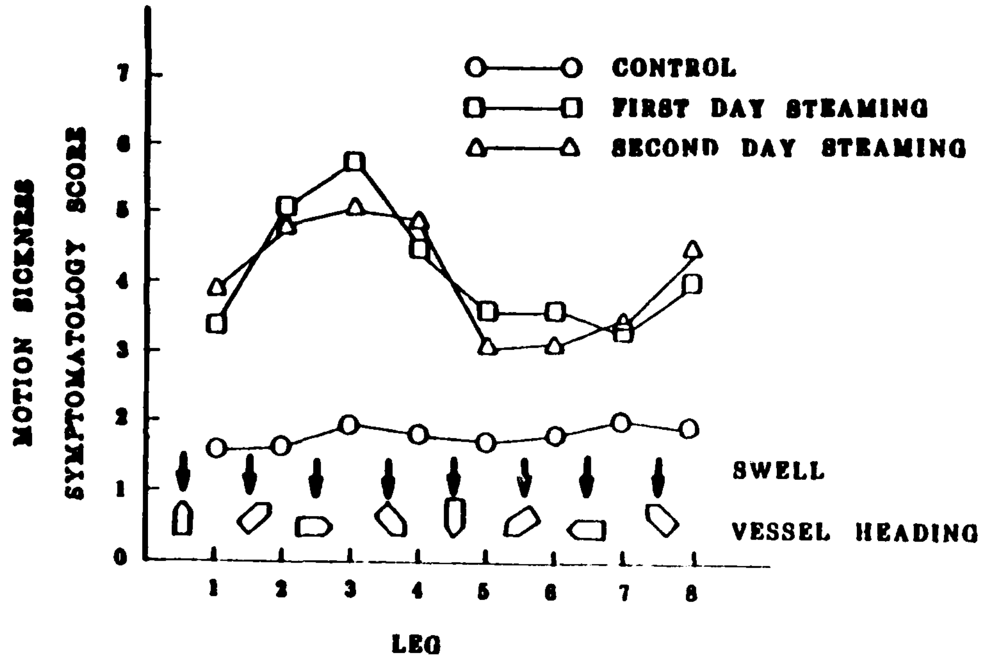

Figure 1: Motion Sickness Symptomatology Severity per Octagonal Steaming Leg (taken from Wiker and Pepper, 1978)

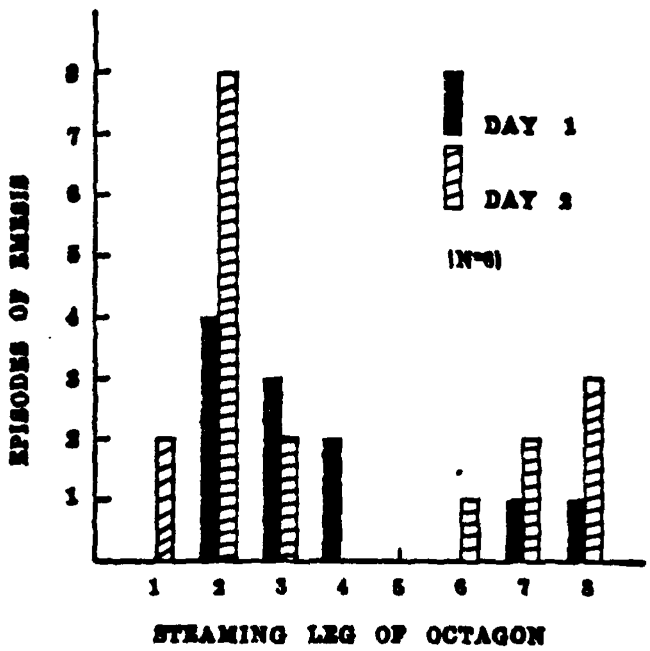

Figure 2: Episodes of Emesis per Octagonal Steaming Leg (taken from Wiker and Pepper, 1978)

Wiker, Pepper and McCauley [Ref. 2] utilized the previously mentioned MSSS score in their evaluations of the WPB, WHEC and SSP. Using a regression technique similar to a one-way analysis of variance, their findings indicated a significant increase in MSSS reports from dockside control to steaming conditions aboard the WPB. Although one subject voluntarily withdrew from the test after two hours of exposure to motions aboard the WPB, 16 subjects exhibited 89 separate episodes of emesis in the three days that the vessel was underway. Only one test subject did not vomit during eight hours aboard the WPB. However, he experienced moderate to

severe levels of nausea. In contrast to this, there were no significant increases in MSSS scores from dockside to steaming conditions aboard the WHEC or the SSP, as shown in Figure 3.

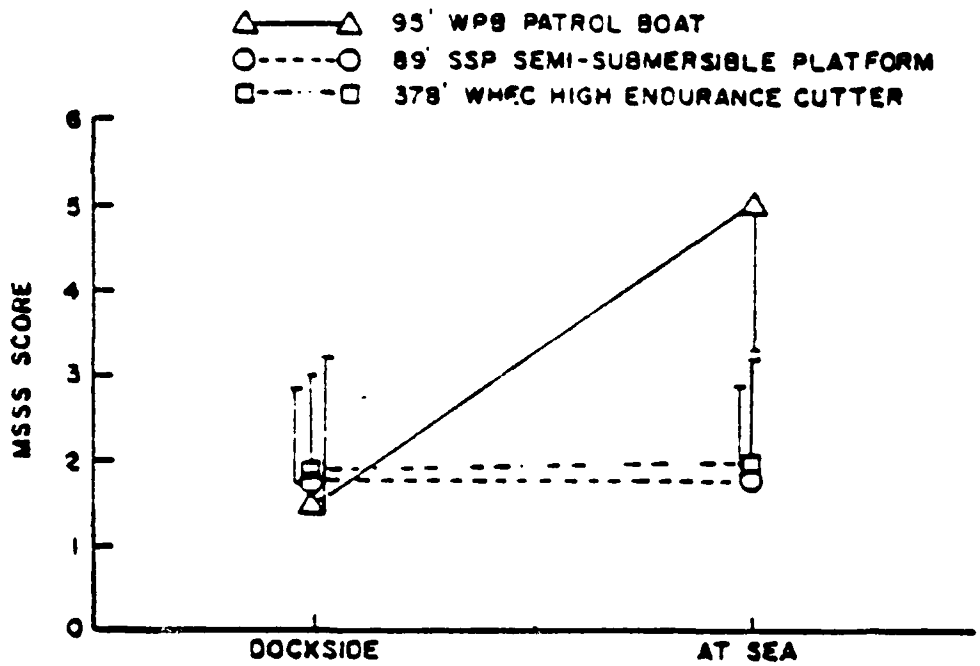

Figure 3: Mean response and standard error of motion sickness symptomatology severity scores as a function of vessel class and testing condition (taken from Wiker, Pepper and McCauley, 1980).

Figure 4 of Annex A shows a plot of MSSS scores versus time of day for all three vessel classes. The higher MSSS scores achieved by the test subjects while aboard the WPB is clearly evident.

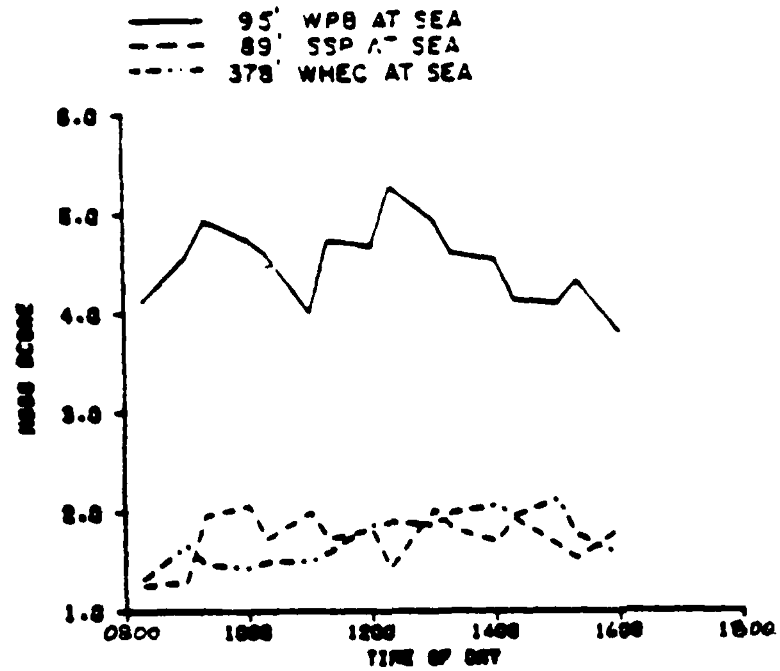

Figure 4: Average motion sickness symptomatology severity (MSSS) scores for each vessel class during days at sea (taken from Wiker and Pepper, 1978).

In conjunction with the studies conducted by Malone [Ref. 20], Thomas et al. [Ref. 21] recorded the following data about the test subjects. Out of 19 subjects used in the experiments, 14 aborted specific tasks due to emesis. Two subjects aborted at least one task because of continued severe nausea (emesis not observed). One subject was used as a substitute on only one trial, and he exhibited no signs of motion sickness. Only two subjects completed all required tasks. Neither of these experienced an episode of emesis. During all sea state 3

simulations, 22 percent of the subjects experienced at least one episode of emesis. For sea states 4 and 5, this percentage increased to 62 percent and 73 percent respectively, as indicated in Table I.

TABLE I

The Ratio and Percentage of the Volunteers Who Vomited at Some Time During the Condition

Condition	July	August	September	Totals
SS3*	2/7	1/5	1/6	4/18 = 22%
SS4*	3/5	0/0	5/8	8/13 = 62%
SS5*	0/0	3/6	5/7	8/11** = 73%
0.3 Hz 0.19G	0/0	3/5	0/0	3/5 = 60%

* Refers to any amplitude level within the condition, ranging from 64% to 100% of the heave acceleration.

** Although the monthly totals in SS5 are correct, two individuals were re-exposed to SS5 in September, for a total of only 11 individuals.

(Taken from Malone, 1980)

Subjects who experienced one episode of emesis during a task continued to have successive episodes until the task was completed or was aborted. No subject voluntarily aborted a run for any reason other than motion sickness. All subjects recovered from the effects of motion sickness when the motion was discontinued; however, some subjects reported feelings of vertigo for a few hours afterward.

E. AFFECTIVE STATE

Wiker and Pepper [Ref. 3] reported that exposure to vessel motion led to significant ($p < .01$) increases in test subjects' reports of fatigue, as shown in Table II.

TABLE II

Summary of Significance Levels from Analysis of Variance of Mood Adjective Checklist Scores (taken from Wiker and Pepper, 1978).

	DAY	HOUR	D X H
Concentration	N.S.	$p < .05$	N.S.
Skepticism	N.S.	$p < .05$	N.S.
Fatigue	$p < .01$	N.S.	$p < .05$
Anxiety	N.S.	N.S.	$p < .01$
Aggression	N.S.	N.S.	N.S.
Vigor	N.S.	N.S.	N.S.
Elation	N.S.	N.S.	N.S.
Egotism	N.S.	N.S.	N.S.
Sadness	N.S.	N.S.	N.S.
Surgency	N.S.	N.S.	N.S.

Since fatigue did not vary with steaming leg or motion sickness severity, they theorized that it must be due to the increased demands on a subject's posture caused by the motion of the WPB. Although there were some changes in test subjects' reports of concentration, skepticism and anxiety during the course of a steaming day, none of these were statistically significant. These results are presented in Table III.

TABLE III

Comparison of Mood Dimensions: Control vs. At-Sea

	Control vs. Sea 1	Control vs. Sea 2	Sea 1 vs. Sea 2
1. Fatigue	Sign. Increase	Sign. Increase	N.S. Decrease
2. Skepticism	N.S. Increase	N.S. Decrease	N.S. Decrease
3. Concentration	N.S. Increase	N.S. Decrease	N.S. Decrease
4. Anxiety	N.S. Increase	N.S. Increase	N.S. Decrease

Note: A two-tailed test with a critical value of $p < .05$ was employed in all comparisons (see Winer, 1971, p. 201 for details).

(Taken from Wiker and Pepper, 1978)

Wiker, Pepper and McCauley's [Ref. 2] studies involving the WPB, WHEC and SSP reveal somewhat different results. Test subjects' mood adjective check lists (MACL's) showed no significant changes in moods from dockside to steaming conditions aboard the SSP. Subjects tested aboard the WHEC showed only a small increase in reports of sadness, social affection and surgency. However, significant changes in all moods except egotism, skepticism and social affection were recorded aboard the WPB while at sea. The scores for these tests and their statistical significance are presented in Tables IV through VI.

TABLE IV

Comparisons Between Dockside and At-Sea Means for Affective State Dimensions Measured Aboard the SSP.

Measure	Dockside $\bar{X} \pm SE$	At Sea $\bar{X} \pm SE$	R^2	Source	SS	df	MS	F
Aggression	0.45 ± 0.52	0.21 ± 0.52	0.0005	Treatment Residual	0.07 147.28	1 542	0.07 0.27	0.3
Anxiety	0.38 ± 0.63	0.39 ± 0.63	0.0005	Treatment Residual	0.10 181.63	1 542	0.10 0.34	0.3
Concentration	1.51 ± 1.02	1.59 ± 1.02	0.002	Treatment Residual	0.98 566.69	1 542	0.98 1.05	0.9
Egotism	0.50 ± 0.73	0.50 ± 0.73	0.0001	Treatment Residual	0.53 5249	1 542	0.53 9.68	0.05
Elation	0.57 ± 0.53	0.52 ± 0.53	0.002	Treatment Residual	0.92 153.03	1 542	0.92 0.28	1.0
Fatigue	0.77 ± 0.92	0.80 ± 0.92	0.0003	Treatment Residual	0.24 463.16	1 542	0.24 0.85	0.2
Sadness	0.14 ± 0.48	0.19 ± 0.48	0.003	Treatment Residual	0.34 125.72	1 542	0.34 0.23	1.5
Skepticism	0.30 ± 0.50	0.26 ± 0.50	0.002	Treatment Residual	0.23 135.5	1 542	0.23 0.25	0.9
Social Affection	0.51 ± 0.69	0.48 ± 0.69	0.0006	Treatment Residual	0.15 256.66	1 542	0.15 0.47	0.3
Surgency	0.67 ± 0.66	0.68 ± 0.66	0.00002	Treatment Residual	0.01 237.87	1 542	0.01 0.44	0.01
Vigor	1.10 ± 0.93	1.03 ± 0.93	0.001	Treatment Residual	0.60 470.6	1 542	0.60 0.87	0.7

* $p < .05$
** $p < .01$
*** $p < .001$

Note: Moods were scored as -- 0- Definitely Not 1- Undecided 2- Slightly 3- Definitely

(Taken from Wiker, Pepper and McCauley, 1980)

TABLE V

Comparisons Between Dockside and At-Sea Means for Affective State Dimensions Measured Aboard the WHEC.

Measure	Dockside $\bar{X} \pm SE$	At Sea $\bar{X} \pm SE$	R^2	Source	SS	df	MS	F
Aggression	0.23 ± 0.56	0.25 ± 0.56	0.0005	Treatment Residual	0.88 167.77	1 542	0.88 0.31	0.03
Anxiety	0.28 ± 0.47	0.24 ± 0.47	0.002	Treatment Residual	0.28 117.82	1 542	0.28 0.22	1.3
Concentration	1.52 ± 1.06	1.5 ± 1.06	0.00005	Treatment Residual	0.03 613.93	1 542	0.03 1.13	0.03
Egotism	0.55 ± 0.75	0.52 ± 0.75	0.0005	Treatment Residual	0.16 305.30	1 542	0.16 0.56	0.3
Elation	0.45 ± 0.54	0.42 ± 0.54	0.0007	Treatment Residual	0.11 157.44	1 542	0.11 0.29	0.4
Fatigue	0.86 ± 0.93	0.90 ± 0.93	0.0004	Treatment Residual	0.21 470.26	1 542	0.21 0.87	0.2
Sadness	0.09 ± 0.38	0.19 ± 0.38	0.02	Treatment Residual	1.27 78.11	1 542	1.27 0.14	8.8**
Skepticism	0.33 ± 0.51	0.26 ± 0.51	0.005	Treatment Residual	0.67 139.57	1 542	0.67 0.26	2.6
Social Affection	0.33 ± 0.63	0.46 ± 0.63	0.01	Treatment Residual	2.40 215.19	1 542	2.40 0.40	6.0*
Surgency	0.61 ± 0.73	0.74 ± 0.73	0.008	Treatment Residual	2.40 286.54	1 542	2.40 0.53	4.5*
Vigor	1.14 ± 0.92	1.09 ± 0.92	0.0009	Treatment Residual	0.40 460.22	1 542	0.40 0.85	0.5

* $p < .05$
** $p < .01$

Note: Moods were scored as -- 0 Definitely Not, 1- Undecided, 2- Slightly, 3- Definitely

(Taken from Wiker, Pepper and McCauley, 1980)

TABLE VI

Comparisons Between Dockside and At-Sea Means for Affective State Dimensions Measured Aboard the WPB.

Measure	Dockside $\bar{X} \pm SE$	At Sea $\bar{X} \pm SE$	R^2	Source	SS	df	MS	F
Aggression	0.21 ± 0.78	0.60 ± 0.78	0.01	Treatment Residual	4.55 323.35	1 526	4.55 0.62	7.4**
Anxiety	0.36 ± 0.70	0.80 ± 0.70	0.10	Treatment Residual	29.80 258.17	1 526	29.80 0.49	60.7***
Concentration	1.52 ± 0.96	1.12 ± 0.96	0.04	Treatment Residual	21.27 489.62	1 526	21.27 0.93	22.9***
Egotism	0.40 ± 0.65	0.38 ± 0.65	0.0003	Treatment Residual	0.08 224.82	1 526	0.08 0.43	0.2
Elation	0.51 ± 0.57	0.20 ± 0.57	0.07	Treatment Residual	12.72 168.54	1 526	12.72 0.32	39.7***
Fatigue	1.00 ± 0.93	1.83 ± 0.93	0.17	Treatment Residual	90.17 454.98	1 526	90.17 0.86	104.2***
Sadness	0.18 ± 0.70	0.71 ± 0.70	0.13	Treatment Residual	36.44 255.59	1 526	36.44 0.49	75.0***
Skepticism	0.43 ± 0.74	0.52 ± 0.74	0.004	Treatment Residual	1.25 287.90	1 526	1.25 0.55	2.3
Social Affection	0.45 ± 0.64	0.37 ± 0.64	0.004	Treatment Residual	0.90 214.40	1 526	0.90 0.41	2.2
Surgency	0.62 ± 0.57	0.14 ± 0.57	0.15	Treatment Residual	31.24 181.12	1 526	31.24 0.34	90.7***
Vigor	0.96 ± 0.77	0.29 ± 0.77	0.16	Treatment Residual	60.14 310.38	1 526	60.14 0.59	101.9***

* $p < .05$
** $p < .01$
*** $p < .001$

Note: Moods were scored as -- 0- Definitely Not 1- Undecided 2- Slightly 3- Definitely

(Taken from Wiker, Pepper and McCauley, 1980).

C. PERFORMANCE

1. Tracking Tasks

McLeod et al. [Ref. 19] concluded that tracking is worse during periods of motion. Every subject in both test groups took longer to acquire the target ($p < .01$), and each had a greater error once the target was acquired ($p < .01$), as shown in Figure 5. However, they determined that the onset of nausea was not the cause of the degradation in the test subject's performance. Performance began to decline as soon as the test cabin was set in motion, but performance was no worse 50 minutes later. If the degradation in performance were due to motion sickness, it would continue to decline over time.

The results of the critical tracking task administered by Wiker and Pepper [Ref. 3] to test subjects aboard the WPB showed a significant drop in performance from dockside testing to testing at sea the first day. However, during the second day at sea, test subjects' performances started to improve to control levels. Additionally, critical tracking test scores seemed to change more with time of day rather than vessel motion. These results are shown in Tables VII and VIII.

Wiker, Pepper and McCauley [Ref. 2] obtained similar results with their tests. Test subjects exhibited a reduced critical tracking bandwidth ($p < .001$) while on board the WPB during days at sea. However, their performance between dock-side and at sea levels remained unchanged aboard the WHEC

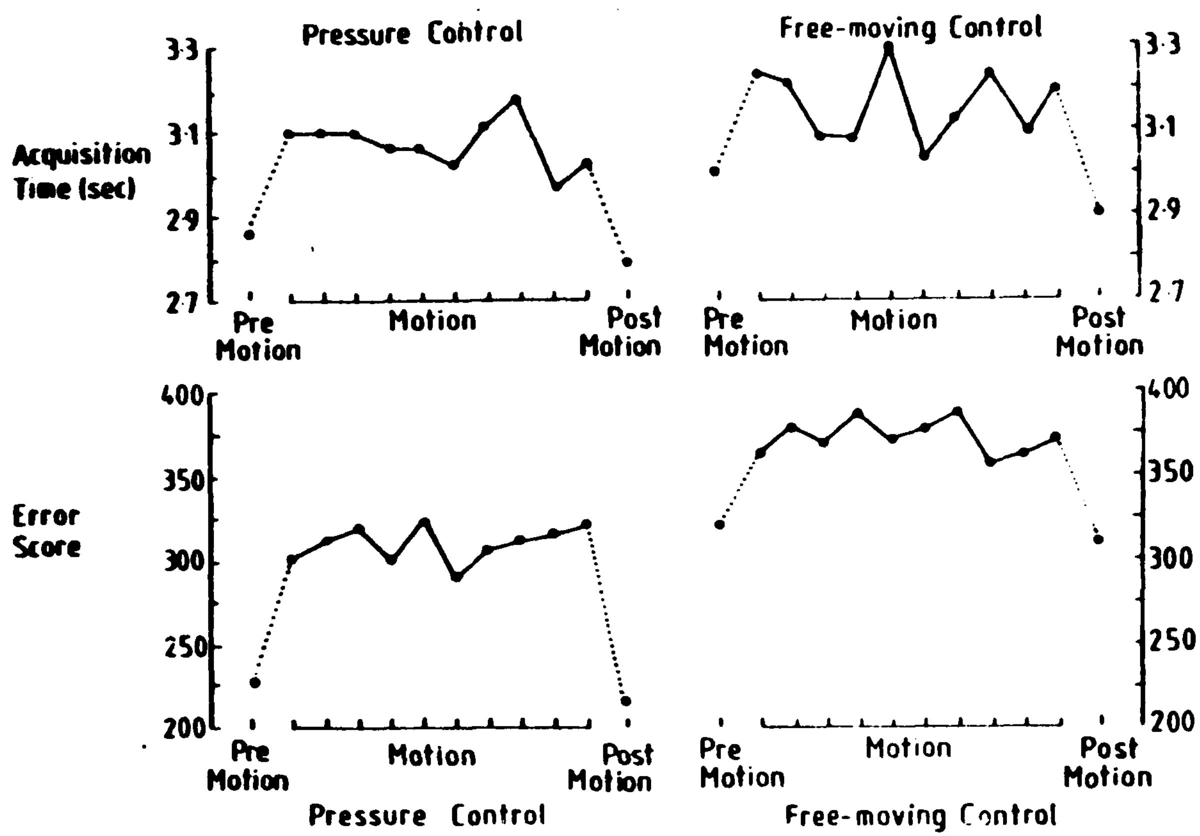

Figure 5: The results of the tracking experiment. The two left hand graphs show the data from the pressure control. The free-moving results are on the right. The two upper graphs show the acquisition time; the two lower ones show the error score. (Taken from McLeod et al., 1980)

TABLE VII

Summary of Results Obtained from ANOVAs on Performance Data on 95' WPB

Performance Task	Metric	Influence of Vsl. Motion	Main Effects		Interactions
			Day	Hour	D x H
Critical Tracking	λ_c (SQRT Transform)	Change with Time of Day	N.S.	.001	.05
Navigation-Plotting	# Correct	Increased errors Changed with Time of Day	.01	.025	N.S.
Letter Search	# Attempted				
1 Letter	unit time	Performance Degraded	.01	.001	.001
2 Letter	unit time		N.S.	N.S.	.001
4 Letter	unit time	Performance Improved	.05	.01	N.S.
Spoke Test	Time to Complete in Seconds (Log Transform)				
Control		Changed Over Time of Day	N.S.	.001	N.S.
Experimental			N.S.	.01	.05
Exp-Control			N.S.	.05	.01

Note: Significant F ratios were converted to probability values and entered under the main effects or interactions column. Those values which did not reach the $p < .05$ level of significance are indicated by N.S. (Taken from Wiker and Pepper, 1978).

TABLE VIII

Comparison of Task Performance: Control Versus At-Sea for 95' WPB

Performance Task	Control vs. Sea 1	Control vs. Sea 2	Sea 1 vs. Sea 2
Critical Tracking Task (λ_c)	Sign. Decrement	N.S. Decrement	N.S. Decrement
Navigation Plotting (% Correct)	N.S. Decrement	Sign. Decrement	Sign. Decrement
Letter Search (# Attempted)			
1 Letter	Sign. Decrement	N.S. Improvement	Sign. Improvement
2 Letter	N.S. Decrement	N.S. Improvement	N.S. Improvement
4 Letter	N.S. Improvement	Sign. Improvement	N.S. Improvement
Spoke Test (Time)			
Control	N.S. Decrement	N.S. Improvement	N.S. Improvement
Experimental	N.S. Decrement	N.S. Improvement	N.S. Improvement
Difference	N.S. Decrement	N.S. Improvement	N.S. Improvement

Note: Dunnett's t-test was conducted to examine changes between control and treatment groups. A two-tailed test with $p < .05$ as a criterion was employed to determine the significance of the differences obtained (Taken from Wiker and Pepper, 1978).

and SSP. The best tracking performance was found aboard the WHEC while the worst was found aboard the WPB. Test scores and their statistical significance are presented in Tables IX through XI.

Malone et al. [Ref. 20] discovered that performance began to decline on the ECM tracking task when test subjects were exposed to approximately 0.10 g. rms of heave aboard the SES simulator. Performance continued a downward trend, reaching a maximum 15 to 20 percent decrement between 0.15 to 0.30 g. rms. Other results obtained were that a test subject's performance generally improves with experience in a given sea state, that the better test performers seem to adapt more readily to vessel motions and that performance can be maintained at levels analogous to the given motion condition until severe nausea and emesis occur. A summary of these results is contained in Table XII.

Results of Malone's [Ref. 20] dual-axis tracking task are also presented in Table XII and reveal that all test subjects showed a degradation in tracking accuracy during simulated motion. A degradation of 16 percent during sea state 3 to 56 percent during sea state 5 was documented. In addition, vertical tracking accuracy was almost 40 percent worse than horizontal tracking accuracy in all sea states and static tests.

TABLE IX

Comparisons Between Dockside and At-Sea Means for Performance Measures Taken Aboard the WPB

Measure	Dockside $\bar{X} \pm SE$	At Sea $\bar{X} \pm SE$	R^2	Source	SS	df	MS	F
Code Substitution (Attempts)	86.3 ± 16.7	73.3 ± 16.7	0.13	Treatment Residual	10991 71446	1 257	10991 278	39.5***
Complex Counting (% Correct)	46.9 ± 23.4	33.2 ± 23.4	0.07	Treatment Residual	110057 1277466	1 233	110057 5483	20.1***
Critical Tracking (λ)	4.9 ± 2.5	4.1 ± 2.5	0.24	Treatment Residual	3080 9648	1 246	3080 39	78.9***
Navigation Plotting (Attempts)	26.1 ± 7.1	20.6 ± 7.1	0.13	Treatment Residual	1958 12791	1 252	1958 50.8	38.6***
Navigation Plotting (# Correct)	19.4 ± 5.9	15.6 ± 5.9	0.09	Treatment Residual	909 8820	1 252	909 35	25.9***
Spoke Test Control Time (Sec.)	29.5 ± 5.1	33.0 ± 5.1	0.11	Treatment Residual	783 6638	1 257	783 25.8	30.3***
Spoke Test Experimental Time (Sec.)	104.1 ± 20.1	112.5 ± 20.1	0.04	Treatment Residual	4097 102811	1 254	4097 404.8	10.1***
Spoke Test Difference Time (Sec.)	75.1 ± 18.8	79.8 ± 18.8	0.02	Treatment Residual	1427 90333	1 254	1427 255.6	4.0*
Time Estimate (12 sec. interval)	11.4 ± .12	10.9 ± .12	0.02	Treatment Residual	0.028 1.49	1 223	0.028 0.007	4.2*

* $p < .05$
** $p < .01$
*** $p < .001$

(Taken from Wiker, Pepper and McCauley, 1980)

TABLE X

Comparisons Between Dockside and At-Sea Means for Performance Measures Taken Aboard the SSP

Measure	Dockside $\bar{X} \pm SE$	At Sea $\bar{X} \pm SE$	R^2	Source	SS	df	MS	F
Code Substitution (Attempts)	84.5 ± 15.6	85.1 ± 15.6	.00	Treatment Residual	31 64619	1 264	31 245	0.1
Complex Counting (% Correct)	36.8 ± 24.5	38.6 ± 24.5	.00	Treatment Residual	45 142259	1 237	45 600.3	0.1
Critical Tracking (λ_c)	5.0 ± 2.4	4.9 ± 2.4	.01	Treatment Residual	72 9182	1 264	72 35	2.1
Navigation Plotting (Attempts)	25.4 ± 6.7	26.5 ± 6.7	.01	Treatment Residual	75 11536	1 258	75 45	1.7
Navigation Plotting (# Correct)	19.0 ± 5.5	19.5 ± 5.5	.00	Treatment Residual	15 7888	1 258	15 30.6	0.5
Spoke Test Control Time (Sec.)	29.7 ± 4.0	30.4 ± 4.0	.01	Treatment Residual	37 4224	1 264	37 16	2.3
Spoke Test Experimental Time (Sec.)	105.4 ± 18.8	101.1 ± 18.8	.01	Treatment Residual	1214 93946	1 264	1214 355.9	3.4*
Spoke Test Difference Time (Sec.)	75.7 ± 17.9	70.7 ± 17.9	.02	Treatment Residual	1674 84197	1 264	1674 318.9	5.3*
Time Estimation (12 sec. interval)	10.0 ± 0.1	9.9 ± 0.1	.01	Treatment Residual	0.009 1.657	1 240	0.009 0.0069	1.3

* $p < .05$
** $p < .01$
*** $p < .001$

(Taken from Wiker, Pepper and McCauley, 1980)

TABLE XI

Comparisons Between Dockside and At-Sea Means for Performance Measures Taken Aboard the WHEC

Measure	Dockside $\bar{X} \pm SE$	At Sea $\bar{X} \pm SE$	R^2	Source	SS	df	MS	F
Code Substitution (Attempts)	83.0 ± 14.4	84.6 ± 14.4	0.003	Treatment Residual	180 55188	1 265	180 208.3	0.9
Complex Counting (% Correct)	46.4 ± 25.8	43.9 ± 25.8	0.002	Treatment Residual	3519 1564257	1 234	3519 6685	0.5
Critical Tracking (λ)	4.8 ± 2.4	4.9 ± 2.4	0.002	Treatment Residual	18 9016	1 265	18 34	0.5
Navigation Plotting (Attempts)	24.3 ± 6.3	26.9 ± 6.3	0.04	Treatment Residual	432 10180	1 259	432 39.3	10.9***
Navigation Plotting (# Correct)	18.2 ± 5.3	20.3 ± 5.3	0.04	Treatment Residual	299 7379	1 259	299 28.5	10.5***
Spoke Test Control Time (Sec.)	29.9 ± 3.8	28.8 ± 3.8	0.02	Treatment Residual	77 3736	1 265	77 14.1	5.5*
Spoke Test Experimental Time (Sec.)	104.1 ± 18.8	98.8 ± 18.8	0.02	Treatment Residual	1868 93387	1 265	1868 352	5.3*
Spoke Test Difference Time (Sec.)	74.2 ± 18.6	70.0 ± 18.6	0.01	Treatment Residual	1185 92119	1 265	1185 348	3.4
Time Estimation (12 sec. Interval)	10.4 ± 0.1	10.9 ± 0.1	0.02	Treatment Residual	0.036 2.293	1 253	0.036 0.009	4.0*

* $p < .05$
** $p < .01$
*** $p < .001$

(Taken from Wiker, Pepper and McCauley, 1980)

TABLE XII

Comparison of Task Performance:
Control Versus At-Sea for SES Simulated Motion

Performance Task	Control vs. SS3	Control vs. SS4	Control vs. SS5
ECM Tracking (Critical Instability Level, λ_c)	Sign. Decrement	Sign. Decrement	N.S. Decrement
Dual Axis Tracking (Time on Target)	Sign. Decrement	Sign. Decrement	Sign. Decrement
Keyboard			
(Mean Computation Time)	Sign. Decrement	Sign. Decrement	Sign. Decrement
(# Errors)	No Change	No Change	No Change
(# Restarts)	No Change	No Change	No Change
Navigation-Plotting (Avg. Distance Error)	N.S. Decrement	N.S. Decrement	N.S. Decrement
Cryptographic Coding (Mean Minute-Rate)			
Decoding	N.S. Decrement	N.S. Decrement	N.S. Decrement
Encoding	N.S. Decrement	N.S. Decrement	Sign. Decrement

2. Tracing Task

McLeod et al. [Ref. 19] have documented that all test subjects showed significant decrements in performance while trying to reproduce the tracing patterns under motion. Although there was a small increase in time to reproduce each tracing, this was not found to be statistically significant. The results of this test are depicted in Figure 6.

3. Digit Keying Tasks

The results of McLeod's [Ref. 19] digit keying task revealed that half of the subjects tested were faster under motion, while half were slower. Therefore, he concluded that any differences in mean keying time were chance occurrences. Also, while there was a small increase in errors in task completion under motion, the increase was deemed not statistically significant.

The keyboard task conducted by Malone [Ref. 20] revealed similar results for simulated SES motions. Under static conditions, median computation time for the task improved from 125 seconds to 80 seconds. This would indicate some amount of learning achieved by the test subjects. Additionally, subjects achieved less than 1.0 computing errors per problem. For the two test subjects who completed all the tasks, motion increased computation time by 24 percent under sea state 4 conditions (see Table XII). Finally, if test subjects reported no symptoms of motion sickness while in sea state 4 conditions, they maintained performance to within

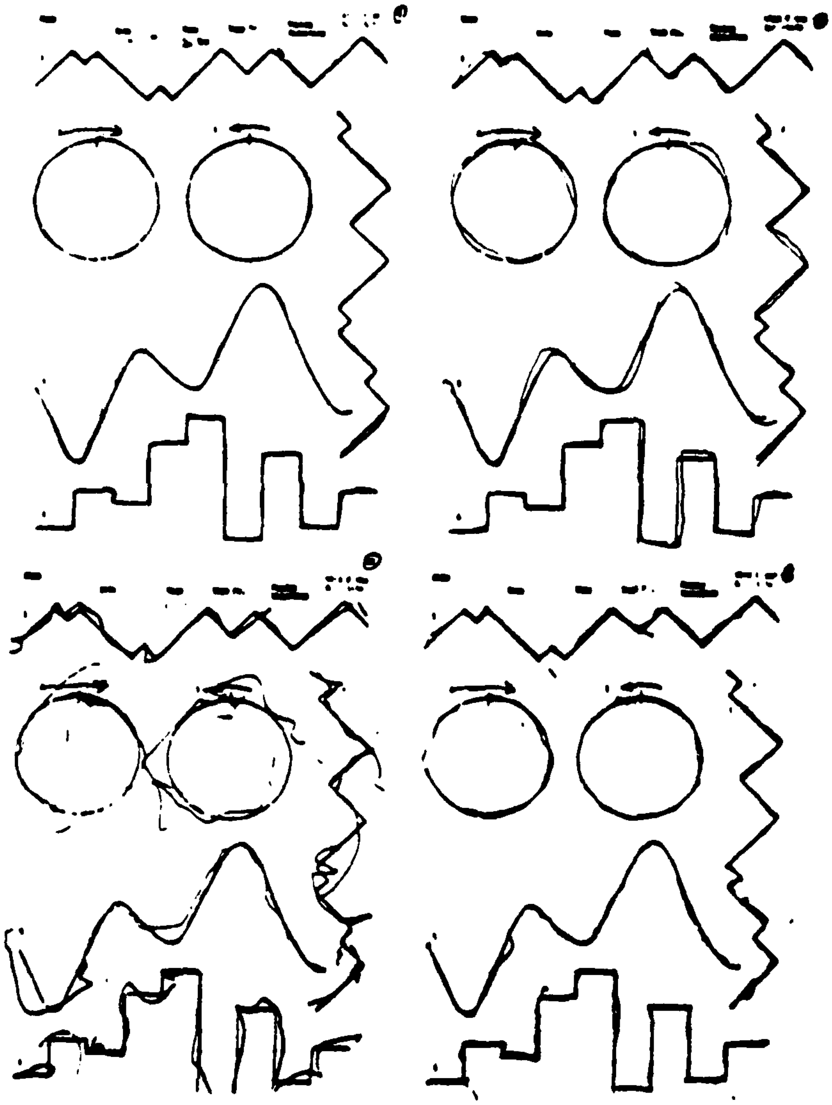

Figure 6: Four attempts to follow the tracing pattern. The upper two were done with the cabin stationary, the lower two while it was under motion. They show the approximate range from best to worst under both conditions. (Taken from McLeod et al., 1980)

20 percent of static levels. However, if they reported severe motion sickness, performance declined more than 40 percent from static levels.

4. Navigation-Plotting Tasks

In Wiker and Pepper's [Ref. 3] preliminary studies aboard the WPB, navigation-plotting performance declined slightly during the first day at sea and continued to decline further on the second day ($p < .01$), as shown in Table VIII. Various t-test analyses on steaming leg combinations showed that greater navigation-plotting accuracy ($p < .05$) occurred when seas were on the stern or abaft the beam.

Wiker, Pepper and McCauley's [Ref. 2] vessel comparison studies again showed severe decrements in test subject performance on the navigation-plotting task while aboard the WPB at sea, as indicated in Table IX. There was a 20 percent reduction in the number of problems completed and correct solutions submitted while aboard the WPB at sea. The WHEC test subjects showed a statistically significant ($p < .001$) increase in the number of correct solutions submitted at sea as compared to the number of correct solutions submitted at the pier. These results are somewhat surprising and are presented in Table XI. SSP test subjects submitted virtually the same number of correct solutions at sea and at the pier with a small overall improvement in navigation-plotting accuracy exhibited while at sea. This is indicated in Table X.

Although the navigation-plotting tasks administered by Malone et al. [Ref. 20] were not as extensive as those used by Wiker and Pepper, several results seemed to indicate that performance was indeed sensitive to the effects of motion. The difference between each test subject's scores for first and second day static tests was compared to the difference between the subject's first and second day motion tests. Although Table XII shows that there was no statistically significant mean change in performance measured in any sea state, each and every test subject's performance declined from the first to the second day during exposure to motion. Additionally, any subject who experienced motion sickness during the test failed to complete the task.

5. <u>Letter Search Task</u>

Wiker and Pepper [Ref. 3] determined that vessel motion contributed to some degradation of performance in the single letter search. However, motion had no significant effect on the two-letter search, and performance actually improved while underway on the four-letter search task, as indicated in Tables VII and VIII.

6. <u>Spoke Test</u>

The Spoke test attempts to define three performance metrics. These are: a motor performance called a control phase, a search and tap phase that includes the search requirement and a difference score that attempts to separate the motor performance from the search and tap phase [Ref. 3].

Wiker and Pepper's preliminary tests aboard the 95' WPB indicated that vessel motion had no significant effect on times to complete the control phase, search and tap phase or the difference score. However, time of day had a significant statistical effect on all three of these performance metrics. These results are presented in Tables VII and VIII.

The vessel class studies conducted by Wiker, Pepper and McCauley [Ref. 2] led to slightly different results. Control phase times from dockside to steaming conditions were unaffected by motion aboard the 378' WHEC and the 89' SSP, while these times increased aboard the WPB at sea when compared to the times recorded at the pier. Times to complete the search and tap phase decreased at sea aboard the SSP and WHEC. However, times increased aboard the WPB when compared to dockside values. Difference scores decreased aboard the SSP, did not change aboard the WHEC and increased aboard the WPB when compared to the dockside control data. Test scores and ANCOVA results are presented in Tables IX through XI.

7. <u>Complex Counting Task</u>

In the preliminary studies aboard the WPB, no significant differences between dockside and steaming data were recorded for the low and medium tones (see Table XIII). Low tone counting showed a significant ($p < .05$) hour effect, while no such result was observed for the medium tone. However, both low and medium tone counting showed a significant ($p < .05$) day and hour effect, as indicated in Table XIV.

TABLE XIII

Comparison of Task Performance: Control Versus At-Sea for 95' WPB

Performance Task	Control vs. Sea 1	Control vs. Sea 2	Sea 1 vs. Sea 2
Complex Counting (Error)			
Low Tone	N.S. Decrement	N.S. Improvement	N.S. Decrement
Medium Tone	N.S. Decrement	N.S. Improvement	N.S. Improvement
Code Substitution (# Attempted)	No Change	N.S. Decrement	N.S. Decrement
Grammatical Reasoning			
(# Attempted)	Sign. Decrement	N.S. Improvement	N.S. Improvement
(# Correct)	N.S. Improvement	Sign. Improvement	N.S. Improvement

Note: Dunnett's t-test was conducted to examine changes between control and treatment groups. A two-tailed test with $p < .05$ as a criterion was employed to determine the significance of the differences obtained (Taken from Wiker and Pepper, 1978).

TABLE XIV

Summary of Results Obtained from ANOVAs
on Performance Data on 95' WPB

Performance Task	Metric	Influence of Vessel Motion	Main Effects		Interactions
			Day	Hour	D x H
Complex Counting Low Tone Medium Tone	Absolute Error	Change with Time of Day	N.S. N.S.	.05 N.S.	.05 .05
Code Substitution	# Attempts	No Sign. Change	N.S.	N.S.	.05
Grammatical Reasoning	# Attempted # Correct	No Sign. Change	N.S. N.S.	N.S. N.S.	N.S. N.S.

Note: Significant F ratios were converted to probability values and entered under the main effects or interactions column. Those values which did not reach the $p < .05$ level of significance are indicated by N.S. (Taken from Wiker and Pepper, 1978).

Again, complex counting scores catalogued in Tables X and XI exhibited no performance degradation between dockside and steaming conditions aboard the SSP and WHEC, while low tone counting accuracy decreased approximately 29 percent aboard the WPB when comparing steaming scores to dockside scores.

8. Code Substitution Tasks

Tables XIII and XIV show that during Wiker and Pepper's [Ref. 3] tests aboard the 95' WPB vessel motion had no significant statistical effect on code substitution scores. The only effect they could document was that test subjects did not perform the same on the tests at the same hour from steaming day to steaming day.

Wiker, Pepper and McCauley [Ref. 2] revealed that the number of code substitutions completed remained virtually unchanged from dockside to steaming conditions aboard the WHEC and the SSP, while those made aboard the WPB under the same conditions declined ($p < .001$). Again, these results are shown in Tables IX through XI. The number of substitutions completed declined as the steaming day progressed aboard all three vessels; however, test subjects aboard the WPB performed some 13 percent fewer substitutions than when they were aboard either the WHEC or the SSP.

The encoding and decoding task administered by Malone [Ref. 20], and O'Hanlon et al. [Ref. 22] can be classified as a code substitution task. They concluded that performance on

this task was not affected by vessel motion except during the full day, 40 knot, sea state 5 trial that required subjects to encode messages (see Table XII). Even when test subjects experienced severe nausea, they were able to perform at better than 80 percent of their static levels.

9. <u>Grammatical Reasoning Task</u>

The results of this test revealed a significant decrement in performance when comparing number of items attempted during the first day of steaming with dockside control levels. No significant effect on the number of correct responses was noted. However, just the opposite happened when comparing control data to that taken on the second day at sea. While there was no significant effect on the number of items attempted, a significant improvement in the number of correct responses was recorded, as shown in Table XIII.

10. <u>Time Estimation Test</u>

Results of the time estimation task revealed test subjects experienced a reduction in absolute error when comparing at sea estimates aboard the WPB with those achieved at dockside (see Table IX). Like comparisons showed no changes between dockside and at sea estimates aboard the SSP, while test subjects aboard the WHEC showed an increase in errors between at sea and dockside estimates ($p < .05$). These results are detailed in Tables X and XI. At sea, test subjects' estimates of the 12-second interval tended to be shortest while aboard the SSP and longest while aboard the WPB [Ref. 2].

11. Visual Acuity Test

O'Hanlon, Miller and Royal [Ref. 22] recorded and analyzed the results of the visual acuity test. They determined that vessel motion caused an increase in every test subject's visual acuity threshold; that is, a larger character size was required for test subjects exposed to motion than was required during static tests (see Table XV). However, no test subject's visual acuity decreased more than a mean of 0.7 minutes of arc.

12. Lock Task

During static tests, the mean lock opening time was approximately 19 seconds with a 45 percent restart rate. For all motions greater than a low sea state 3, test subjects' opening times increased 10 percent, while restarts increased 38 percent. Although static condition data indicated a continued learning process by the test subjects, a degradation in performance during motion was statistically highly significant ($p < .001$) [Ref. 20]. These results are shown in Table XV.

13. Missile Detection Task

Performance comparisons were made for those subjects who completed the test, and the results showed that test subjects did slightly better on the Pre-test while in the motion environment as opposed to the static environment. Additionally, Long Watch and Post-test results did not differ

TABLE XV

Comparison of Task Performance:
Control Versus At-Sea for SES Simulated Motion

Performance Task	Control vs. SS3	Control vs. SS4	Control vs. SS5
Visual Acuity (Reading Accuracy)	N.S. Decrement	Sign. Decrement	Sign. Decrement
Lock (Time to Open)	Sign. Decrement	Sign. Decrement	Sign. Decrement
Missile Detection (Verified Contact Paints)	N.S. Improvement	N.S. Improvement	N.S. Improvement
Collision Avoidance (% of Collision Course Remaining Before Collision)	No Change	No Data	N.S. Improvement
Maintenance (Weighted Disassembly Rate)	N.S. Decrement	N.S. Decrement	N.S. Decrement

significantly between static and motion conditions, as shown in Table XV. However, these results are somewhat inconclusive since, with the exception of one individual, all subjects who became ill during the task withdrew from the environment before establishing a numerical score [Ref. 20].

14. Collision Avoidance Task

Of nine subjects tested, no statistically significant differences in performance were observed for static tests on the first and second day. Four subjects completed the task under simulated low sea state 3 motion. Results did not differ between days one and two, and performance actually improved over static levels. At high sea state 3, six subjects suffered no performance degradations over static levels. Only two subjects successfully completed the task at full sea state 5, and their performances improved when compared to static scores [Ref. 20]. These results are contained in Table XV.

15. Maintenance Task

The results of the maintenance task varied among test subjects. Approximately 75 percent of the subjects experienced a performance decrement in disassembly rate under motion; however, 25 percent of the test subjects showed a significant improvement under all motion conditions. When averaged, a non-significant decrement (Table XV) was achieved. No systematic effect to the various rates could be determined [Ref. 20].

D. TEST BIASES

Malone [Ref. 20] reports that test scheduling for the SES motion simulator had to be altered due to equipment malfunctions and unplanned design modifications. Moreover, the duration of the tests was also substantially changed as test subjects exercised their option of leaving the simulator upon the onset of severe motion sickness. This led to a partially completed, biased data base with the following characteristics:

1. Several variations of the three designed motion conditions were used while fewer subjects were tested.

2. Almost all performance data was obtained from subjects not experiencing motion sickness, since those that experienced the malady generally aborted the task or exited from the cabin.

3. Due to the high number of test subjects who could not tolerate motion sickness, more six-hour runs were conducted instead of the scheduled 24 to 48 hour runs.

4. Only those subjects who had demonstrated an ability to tolerate severe motion sickness were tested in the more severe motions, leading to data biased with regard to motion sickness resistance.

5. Number and duration of static cabin exposure runs had to be altered because of the disruption in motion cabin runs. This, in turn, caused base line data to be altered.

In the preliminary study, conducted by Wiker and Pepper [Ref. 3] aboard the 95' WPB, data must also be looked at as somewhat biased due to measures beyond the experimenter's control. First, all underway tests were conducted in a relatively mild sea state 2 condition. Additionally, sea state

was not uniform across the same steaming legs due to secondary and tertiary swells or wind shifts. Second, performance measures were not adjusted for a possible lag in response to vessel motion. Finally, the test subjects used were experienced crewmen, and the strong possibility of learning effects due to repeated testing was not discounted.

The vessel comparison studies conducted by Wiker, Pepper and McCauley [Ref. 2] have similar biases. They, too, for the most part, utilized experienced crewmen, and all at-sea trials were performed in sea state 3 conditions. Additionally, two legs of the second octagon were omitted during the first day at sea. This was caused by mechanical problems aboard the 378' WHEC. Average sea heights also increased from the first to the third day of the underway tests. Lastly, test compartment temperatures aboard the WPB and SSP were found to be cooler while the vessels were steaming than when the vessels were tied to the pier.

TABLE XVI

Overall Summary of Results

Vessel Class	Incidence of Motion Sickness in SS3	Affective State Changes	Psychomotor Task Performance Changes at Sea	Test Subjects
89' SSP	None Observed	None	No decrements on any tasks; small improvement on Spoke Test	Experienced
95' WPB	Severe	Severe changes in most every mood; fatigue worst	Significant decrements on most every task	Experienced
378' WHEC	None Observed	Small change; not significant	No decrements on any tasks; significant improvement on Navigation-Plotting	Experienced
HMS AVENGER (Simulated Motion)	None Observed	No Data	Decrements in tasks involving whole arm motions	Inexperienced
2,000 TON SES (Simulated Motion)	Severe	No Data	Significant decrement on Tracking, Keyboard, Lock Opening and Visual Acuity Tests	Inexperienced

V. CONCLUSIONS AND RECOMMENDATIONS

Given the right frequency and duration, motion sickness can affect any individual with an intact and functioning vestibular system. The degree that a person is affected may range from mild nausea to frequent and severe vomiting. The latter case is, or should be, a primary concern to us as decision and policy makers since continued emesis can produce severe dehydration of the human body and possible internal injuries as well. Armed with this knowledge, and cognizant of the widely accepted theory that motion sickness onset is most frequently observed aboard vessels accelerating in the frequency band 0.15 - 0.25 Hz, it is recommended that we attempt to design and build our future Naval combatants so that the performance and well being of our Naval personnel is not degraded.

The number of episodes of emesis and the degradation of test subject performance aboard the 95' WPB clearly show that that particular vessel is not a viable platform from a human factors standpoint. The Coast Guard also has an 82' WPB that this author has had the mixed pleasures to serve aboard. This vessel rode badly in sea states above SS3, and during many search and rescue missions it was not uncommon to find up to 75 percent of the crew incapacitated due to

motion sickness. Given the importance of this mission in the Coast Guard, this can never be an acceptable statistic.

Expanding on the statement that the 95' WPB is not a viable seagoing platform in rough weather, it is this author's personal opinion that most of our seagoing services' typical monohull vessels are very poor in seakeeping ability in sea states above SS4. The reason that this is so stems from the fact that most Naval combatants have a large length-to-beam ratio (typically on the order of seven or nine to one) with a lot of weight (such as weapon systems) high above the ship's center of gravity. The author poses the following solutions to this seakeeping problem. First, the length-to-beam ratio of our Naval combatants should be reduced to possibly three or four to one. Although this would affect the maximum speed a vessel could attain, this author feels that a trade-off could be reached where mission effectiveness would not be compromised. Second, systems that are critical to the successful completion of our Naval mission, and systems that are people-oriented, should, where possible, be placed in areas least affected by vessel motion, such as below the main deck and near the ship's centerline. Finally, ship designers and ship builders should be given a detailed list of specifications, such as a maximum allowable acceleration and corresponding frequency, so that there is no doubt as to what is expected of them and what we as sailors expect as a final product.

The results obtained aboard the Navy's 89' SSP are very encouraging. Although similar in size to the 95' WPB, the SSP personnel suffered no episodes of emesis and no degradation in task performance. The author feels that the major factors in the SSP's fine performance are its twin hull configuration and smaller length-to-beam ratio. The smaller length-to-beam ratio prevents the vessel from rolling as much as, say, the 95' WPB, while the twin hull configuration reduces the severity of pitching and bow slap.

Having served aboard a Coast Guard 378' WHEC, the author feels that the results obtained by Wiker, Pepper and McCauley are somewhat misleading. When these vessels were initially designed, the exhaust stacks topside were built higher. This caused a more violent roll in sea states above sea state 4, which led to increased reports of personnel becoming seasick, as well as frequent reports of personnel injuries caused by motion. By cutting down the stacks and installing anti-roll tanks, the severity of vessel motion was reduced. However, from this author's experience, motion sickness onset was proven to be a debilitating factor for personnel while the WHEC was operating in sea state 5. Thus, although a medium sea state 3 can precipitate motion sickness for personnel on board a vessel such as the 95' WPB, the WHEC must be tested in a more demanding environment to achieve the same accelerations.

The results of the tests using simulated SES motions and a motion generator are also cause for concern. In full sea state 3 and medium sea state 4 conditions, one-third to one-half of the subjects experienced severe nausea or emesis which degraded their ability to perform routine, prolonged mental work and psychomotor tasks. In response to these results, the author is obliged to pose the following question: that is, is it a mission requirement for the SES platform to be able to achieve speeds of 60-80 knots under various sea conditions? Although speed is desirable for a Naval vessel, this author does not feel that the accelerations and vibrations imposed on the vessel and its occupants by high speeds is a viable trade-off in mission performance. If your people are unable to perform, speed is a wasted commodity. Unless it is a mission requirement for the 2,000 ton SES to achieve speeds of 60-80 knots, this author feels that the ship designers and ship builders must be challenged to perfect and produce an SES that can achieve a lesser speed, say, 40 knots in sea states up to 8 feet, while not having the performance of our personnel degraded.

Since there are many vessels currently in the Fleet that can be classified as having poor seakeeping ability, additional measures must be taken to reduce the potential impact on readiness caused by personnel who are prone to seasickness. This author feels that personnel assigned to these ships should be screened to determine their degree of susceptibility

to motion sickness. One such screening process proposed is the Pensacola Motion Sickness Questionnaire, designed specifically for maritime personnel. Those with high levels of susceptibility would then not be assigned to vessels with poor seakeeping ability, thereby decreasing the chance for mission failure due to personnel performance degradations. Another possible screening procedure proposed would involve exposing sailors to simulated vessel motions during boot camp. Although the price of a simulator would be high, the economic trade-off from the information gained could possibly save the service money in the long run. At any rate, it is an avenue worth investigating.

If the hypothesis that anyone with a functioning vestibular system can become seasick under the right conditions is accepted, the author suggests more research should be devoted to the area of motion sickness deterrents. The author concurs with those researchers who have found that task concentration serves to alleviate some of the effects of motion sickness. Additionally, it has been shown by such authorities as W. H. Johnson [Ref. 7] that individuals can decrease the incidence of motion sickness by keeping their heads still to the extent that they are able. Ship designers must therefore ensure that certain work stations be fitted with special seats and headrests if vigilance tasks or other cognitive tasks are to be conducted.

Very little research has been conducted to determine the deterrent effect of various drugs. Motion sickness drugs such as Dramamine have been commercially available for years. However, these drugs must be taken some time before the individual enters the motion environment. Sailors stationed aboard ships are not always afforded this luxury. Although drugs as an antidote for motion sickness may seem like a cop-out, this author feels that it is a very important area for future research and strongly recommends that funds be earmarked for its continued study.

Although personnel performance would be an ideal criteria for evaluating various seagoing platforms, past studies have shown that performance has been inconsistent as a reliable measure of effectiveness. At a workshop on SES motions in 1974, Wesley C. Blair [Ref. 24] summarized the feelings of those in attendance with the following:

> The picture as related to performance is murky at best. Depending on the tasks you get one result or the other and it may not be worth pursuing as design criteria but has promise for potential countermeasure development.

In this comparative study, it was shown that Wiker and Pepper [Ref. 3] observed little or no degradation in performance on those tasks completed by the WPB's existing crew during the initial Pre-test. However, other subjects performed poorly on those same tasks administered by Wiker, Pepper and McCauley [Ref. 2] while under virtually the same motion conditions. In this author's opinion, this seems to corroborate what Blair summarized.

We may, however, extrapolate a little from the results obtained by these men. Given that motion or movement is disruptive to a person performing whole arm movements and fine tuning type adjustments, personnel performing tracking tasks, navigation-plotting tasks, lock opening and maintenance type task will suffer degradations in task performance. The amount of performance decrement will somehow be related to the severity of vessel motion. If the person performing the task is also suffering from motion sickness, performance would probably be degraded further since he or she may have to discontinue a task to overcome the feelings of nausea or to combat an episode of emesis. Personnel performing cognitive tasks such as code substitution, time estimation and complex counting will exhibit performance decrements if they too become seasick. The author feels that this is because those personnel will tend to think about the ill feeling and nausea that they are experiencing rather than devoting full concentration to the task at hand.

If, in this author's opinion, performance degradations are correlated to the degree of motion sickness experienced by an individual and the degree of motion the vessel is subjected to, then a set of baseline data could be compiled by taking a given platform, exposing it to a set of predetermined accelerations and frequencies, and testing a set of subjects with a standardized test battery that would be sensitive to performance variations. This is, in fact, what R. S. Kennedy

[Ref. 25] and a group of researchers are currently attempting to do at the Naval Biodynamics Laboratory in New Orleans, LA. They have developed Performance Evaluation Tests for Environmental Research (PETER) which are a collection of standardized tests that they have administered to "professional" test subjects under non-motion conditions. Although the system is still under refinement and revision, it is the state of the art in assessing human physical and mental capabilities in environments such as ship motion. It is from systems such as PETER that we as researchers may some day predict quite accurately how any given individual will perform in any given motion environment.

Some questions still remain as to why simulated studies differ from actual field tests. This author feels that the preliminary study conducted by Wiker and Pepper [Ref. 3] was somewhat artificial. The test subjects knew that the tests would be conducted for only a few hours. Because of this, they were mentally able to gear themselves up to perform well. Under actual steaming conditions, the crew is not always sure how long a certain mission will last. Hence, they may not be able to continually maintain an adequate level of motivation to complete required tasks.

It is this author's opinion that the simulated SES motion studies conducted by Malone and others were also somewhat tainted. Although the duration of the tests was more realistic, no visual cues were provided to the test subjects in

the enclosed cabin. While stationed aboard a Coast Guard 82' WPB, the author observed that visual cues such as seeing an oncoming wave approach the bow assisted crew members in their ability to adapt to the motion environment. Coincidentally, the only time the author became seasick while on board this vessel occurred during a dark night in a blinding snowstorm when visual cues were not available. Another reason that the simulated SES motion studies results should be qualified is that inconclusive data about performance degradations was obtained by allowing test subjects to depart the cabin upon severe motion sickness onset.

Another question that is not totally resolved to this author's satisfaction is to what degree is performance affected by the onset of motion sickness and to what degree is performance affected by actual vessel motion? It is the author's personal experience that motion sickness impacts most upon those tasks which require long periods of effort or attention, those tasks whose completion are self-paced and those tasks which are normally viewed as non-essential to mission completion. Motion, on the other hand, tends to impact most upon those tasks requiring motor skills. To this author's knowledge, no one has yet been able to determine the individual impact these factors have on task performance when they occur in combination. This is a recommended area for future study.

As stated earlier, this author feels that, based on the comparisons made, the 89' SSP proved to be the superior sea-going platform. Although the 2,000 ton SES simulation did not fare well, a surface effect ship like those currently being designed by such companies as Bell-Halter may prove to be highly effective from a readiness standpoint as well as a human factors standpoint. At any rate, such a craft is recommended as a platform for future motion studies.

APPENDIX A

SEA STATE DEFINITIONS

DEFINITIONS OF SEA CONDITIONS: WAVE AND SEA FOR FULLY ARISEN SEA**

Sea — General		Wind				Sea								
Sea State	Description	(Beaufort) Wind force	Description	Range (knots)	Wind Velocity (knots)	Wave Height: Average	Wave Height: Significant	Wave Height: Average of One-Tenth Highest	Significant Range Periods (sec)	Periods of maximum Energy of Spectra $T_{max} = T_c$	Average Period $\bar{T}_1$	Average Wave-length $\bar{L}_w$ (ft unless otherwise indicated)	Minimum Fetch (nautical miles)	Minimum Duration (hr unless otherwise indicated)
	Sea like a mirror	0	Calm	<1	0	0	0	0	—	—	—	—	—	—
0	Ripples with the appearance of scales are formed, but without foam crests.	1	Light airs	1–3	2	0.04	0.01 0.01	0.09	1.2	0.75	0.5	10 in.	5	18 min
1	Small wavelets, short but pronounced crests have a glossy appearance, but do not break.	2	Light breeze	4–6	5	0.3	0.5	0.6	0.4–2.8	1.9	1.3	6.7 ft	8	39 min
	Large wavelets, crests begin to break. Foam of glossy	3	Gentle	7–10	8.5	0.8	1.3	1.6	0.8–5.0	3.2	2.3	20	9.8	1.7
	appearance. Perhaps scattered with horses.		breeze		10	1.1	1.8	2.3	1.0–6.0	3.2	2.7	27	10	2.4
2					12	1.6	2.6	3.3	1.0–7.0	4.5	3.2	40	18	3.8
	Small waves, becoming larger;	4	Moderate		13.5	2.1	3.3	4.2	1.4–7.6	5.1	3.6	52	24	4.8
	fairly frequent white horses.		breeze	11–16	14	2.3	3.6	4.6	1.5–7.8	5.3	3.8	59	28	5.2
3					16	2.9	4.7	6.0	2.0–8.8	6.0	4.3	71	40	6.6
					18	3.7	5.9	7.5	2.5–10.0	6.8	4.8	90	55	8.3
4	Moderate waves, taking a more	5	Fresh	17–21	19	4.1	6.6	8.4	2.8–10.6	7.2	5.1	99	65	9.2
	pronounced long form; many white horses are formed (chance of some spray).		breeze		20	4.6	7.3	9.3	3.0–11.1	7.5	5.4	111	75	10
5					22	5.5	8.8	11.2	3.4–12.2	8.3	5.9	134	100	12
	Large waves begin to form;	6	Strong	22–27	24	6.6	10.5	13.3	3.7–13.5	9.0	6.4	160	130	14
	white crests are more extensive		breeze		24.5	6.8	10.8	13.8	3.8–13.6	9.2	6.6	164	140	15
6	everywhere (probably some spray).				26	7.7	12.3	15.6	4.0–14.5	9.8	7.0	188	180	17
					28	8.9	14.3	18.2	4.5–15.5	10.6	7.5	212	230	20
	Sea heaps up, and white foam from	7	Moderate	28–33	30	10.3	16.4	20.8	4.7–16.7	11.3	8.0	250	280	23
	breaking waves begins to be blown		gale		30.5	10.6	16.9	21.5	4.8–17.0	11.5	8.2	258	290	24
7	in streaks along the direction of the wind (Spindrift begins to be seen).				32	11.6	18.6	23.6	5.0–17.5	12.1	8.6	285	340	27
					34	13.1	21.0	26.7	5.5–18.5	12.8	9.1	322	420	30
					36	14.8	23.6	30.0	5.8–19.7	13.6	9.6	363	500	34
	Moderate high waves of greater	8	Fresh	34–40	37	15.6	24.9	31.6	6–20.5	13.9	9.9	376	530	37
	length; edges of crests break into		gale		38	16.4	26.3	33.4	6.2–20.8	14.3	10.2	392	600	38
	spindrift. The foam is blown in well-marked streaks along the direction of the wind. Spray affects visibility.				40	18.2	29.1	37.0	6.5–21.7	15.1	10.7	444	710	42
8					42	20.1	32.1	40.8	7–23	15.8	11.3	492	830	47
	High waves. Dense streaks of foam	9	Strong		44	22.0	35.2	44.7	7–24.2	16.6	11.8	534	960	52
	along the direction of the wind. Sea begins to roll. Visibility affected.		gale	41–47	46	24.1	38.5	48.9	7–25	17.3	12.3	590	1110	57
	Very high waves with long over-				48	26.2	41.9	53.2	7.5–26	18.1	12.9	650	1250	63
	hanging crests. The resulting foam	10	Whole*	48–55	50	28.4	45.5	57.8	7.5–27	18.8	13.4	700	1420	69
	is in great patches and is blown in		gale		51.5	30.2	48.3	61.3	8–28.2	19.4	13.8	736	1560	73
	dense white streaks along the direc-				52	30.8	49.2	62.5	8–28.5	19.6	13.9	750	1610	75
	tion of the wind. On the whole, the				54	33.2	53.1	67.4	8–29.5	20.4	14.5	810	1800	81
9	surface of the sea takes on a white appearance. The rolling of the sea becomes heavy and shocklike. Visibility is affected.													
	Exceptionally high waves. Sea completely covered with long white	11	Storm*	56–63	56	35.7	57.1	72.5	8.5–31	21.1	15	910	2100	88
	patches of foam lying in direction of wind. Everywhere edges of wave crests are blown into froth. Visibility affected.				59.5	40.3	64.4	81.8	10–32	22.4	15.9	985	2500	101
	Air filled with foam and spray. Sea white with driving spray. Visibility very seriously affected.	12	Hurri-cane*	64–71	>64	>46.6	>74.5	>94.6	10–35	24.1	17.2	—	—	—

* For hurricane winds (and often whole gale and storm winds) required durations and reports are barely attained. Seas are therefore not fully arisen.

** Revised December 1964 by L. Moskowitz and W. Pierson. Used courtesy of The Navy Oceanographic Office.

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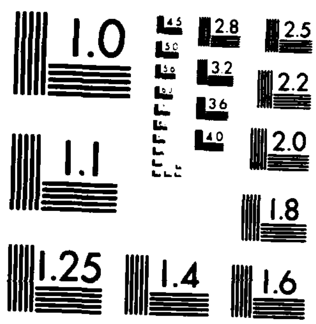

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